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A STUDY OF THOMSEN'S DISEASE, BASED ON EIGHT CASES, IN A FAMILY EXHIBITING REMARKABLE INHERITANCE FEATURES IN THREE GENERATIONS.

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THE rich literature on inherited abnormalities of the neuro-muscular system is notably poor in information regarding any definite physical traits that might be regularly associated with the particular abnormality in the affected family. The human race is too small in numbers, too slow-breeding and too widely dispersed to permit of easy generalizations regarding the linkage of certain physical types with certain constitutional abnormalities. Lombroso's inferences proved to be too far-sweeping, at a time when the working of Mendelian laws was not understood, to say the least.

The value of accumulating information respecting the association of certain gross appearances of person with specific pathological conditions, is obvious. Certainly five, and not improbably six, out of the eight cases observed in the present instance would have remained unrecognized, if it were not for the marked grouping of the affected family into easily distinguishable physical types. Of nine persons comprising one such group, only one came forward with the complaint of myotonia; but the suspicion attaching to certain physical likenesses led to an investigation, with the result that every one of the eight persons examined proved to be myotonic.

In the sixty or seventy reports on myotonia and paramyotonia, a large percentage of the investigators note the co-existence of psychopathies and of the muscular disorder in members of the same family. The muscular and mental disorders sometimes co-exist in the same individual. Thomsen [41] himself emphatically classed myotonia con-

genita with the psychoses. In the first generation of the family to be described, the two disorders indeed co-exist in the same person, but in the second generation there is a clear-cut segregation of the two disorders, each becoming associated with a definite physical type of person; three individuals of a certain type become affected with Thomsen's disease, and the other three, of a different physical type, become affected with psychoses. In the third generation the psychosis, as well as the physical type associated with it, are eliminated. Four new types appear, each represented by one individual who has inherited from a respective parent, not a blood-relation of the affected family, that parent's physical type and normal constitution. The rest of the members of the third generation are all of the myotonic type of the second generation, and they are all, with the possible exception of one who has not been studied, affected with myotonia.

The Mendelian phases of the family to be described may help to throw some light upon two of the pathological features of Thomsen's disease—the abnormally large musculature usually associated with it, and the muscular atrophy which is sometimes observed.

Aside from the Mendelian phases, the cases in question have other interesting features. One such feature has been described by Pelz [32]. Of two brothers observed by this investigator, one was affected with a very pronounced form of Thomsen's disease. The other had no symptoms of myotonia, but the presence of the disorder was ascertained in him by eliciting the characteristic myotonic reaction. Three of the nine cases to be described have to this day suffered no physical discomfort from the disease, which they are almost certain to transmit to their posterity.

Finally, two of the cases are interesting in themselves. One suffers from a form of Thomsen's disease which has greatly facilitated the study, and has to a great extent explained the mechanism, of the abnormal muscular action. The other is an instance, no one knows how rare, in which the manifestations of the disorder are evoked by strong psychical stimuli only. If it were not for the fact that this patient is a member of a myotonic family, and that she belongs to a group of persons marked by certain physical characteristics, the examination would have been inadequate, and her trouble would almost certainly have been regarded as a form of hysteria.

In order to accentuate the Mendelian phases in the forthcoming study, it will be convenient to deviate somewhat from the ordinary form of description. The cases will be taken up not in the order in which

they presented themselves for examination, but according to generations and to groups formed by the inheritance of certain characteristics. Thus the first generation, which was not personally investigated—the grandparents—will be taken up first. The second generation will be described in two groups: one, the myotonic group; the other, the border-line psychosis group. The third generation, too, will appear in two groups: one consisting of normal persons; the other comprising five individuals affected with Thomsen's disease of widely different grades of severity.

The First Generation.

Neither the man nor the woman was seen by the investigator, the data respecting the couple having been obtained from their children.

William L. was born in Worcestershire, England, where he followed in his youth the trade of needle pointing. Some time after his arrival to the United States he became the owner of a beer saloon. He was a man of large size, weighing about 220 lb., and of powerful build. He had a very fair complexion, dark-brown hair and blue-grey eyes. He was much addicted to drink, but otherwise a cheerful, intelligent, kind-hearted man. He is not known by his children to have suffered at any time from muscular rigidity or cramp, nor from any trouble that could be interpreted as "nervousness." In fact he was a very healthy man all his life. He died from pneumonia at the age of 48, nineteen years ago.

Anna H. L., the wife of William L., was born in Derbyshire, England. In appearance she vas of medium stature and build. She had a dark-olive complexion, dark-blue eyes and dark chestnut-coloured hair. She had been a very nervous woman all her life, and in later years suffered from periodic attacks of profound depression of spirits alternating with states of irritability. She "developed" a muscular trouble, which became particularly marked during the last ten or twelve years of her life. In was the occurrence of a cramp or muscular stiffness at times when sudden movements were required. The children particularly remember the following habit: Whenever she travelled in a street car she would rise from her seat while the car was still in motion and at a considerable distance from her destination. If she sat until the car stopped at her destination, the sudden attempt to rise would "bind" her, and the ensuing delay, by attracting to her the attention of the passengers would embarrass her greatly.

She died at the age of 62, six years ago.

The Second Generation.

Of the thirteen children born of the marriage of William L. to Anna, seven died in infancy. The surviving six fall into two groups: the myotonic and the border-line psychosis group.

The Myotonic Group.

Case 1.—Herbert L., aged 33, weight 210 lb. Married and has two children. A garage-man by occupation. In appearance he is a large and powerful-looking man of fair complexion with brown hair and blue-grey eyes. A very healthy man physically, and of the average mental and emotional state. He suffers from a muscular trouble which, however, has not been a source of any great inconvenience. In his business he is sometimes called upon to do heavy lifting. On such occasions his hand becomes "bound" around the object so that he cannot let it go for a number of seconds.

A test of his grip revealed a degree of strength which appeared to be in proportion to his very large musculature. His grasp relaxed easily. He explained, however, that the inability to open his hand occurred only when the grasping action was accompanied by a heavy lifting exertion.

Mechanical stimulation of his muscles by striking them with a percussion hammer resulted in a normal contraction followed by a slow relaxation. This slow relaxation after the cessation of the stimulus was particularly evident in the left biceps and the forearm muscles, and was obtained in a more pronounced form by means of faradic stimulation.

The tendon reflexes were normal.

Case 2.—Louise W. (fig. 1, D), aged 35, weight 228 lb. Married and has given birth to five children, all of whom are living. In appearance she is like her brother Herbert, having the same colour of the skin, hair and eyes. With the exception of occasional pains in the lower limbs and the abnormality to be described, she is in every respect a healthy woman.

She has had one serious illness—an attack of diphtheria at the age of 18, nine months after her marriage. Antitoxin was administered in three doses. Nine days after the onset of the illness she had diplopia, which persisted for four weeks; regurgitation of food through the nostrils, which persisted for six weeks; paralysis of the upper limbs for sixteen weeks: and partial paralysis of the lower limbs (she could move them in bed, but she could not stand up), for eight weeks. Recovery was complete.

Questioned respecting a muscular abnormality, she persisted for weeks in denying the presence of any. The following history was finally elicited:—

At the age of 23, two weeks before the birth of her second child, she had the first attack of a trouble from which she has been suffering ever since. While she was engaged in preparing a meal at the kitchen stove she was badly frightened on seeing her eldest girl, who was then 2 years of age, pulled off a chair by a neighbour's child. As she was about to make an abrupt movement towards the children she suddenly experienced a wave of stiffness run through her. She felt the muscles throughout her body become tense and hard, until she could not balance herself any longer in the erect position, and she fell to the floor "like a log of wood." The rigidity lasted for about three minutes, during which she was perfectly conscious. The muscles relaxed in the course

of another minute or two, and she was quite normal again. Ever since then she has been subject to such attacks whenever suddenly excited or surprised.

The writer witnessed one of these attacks in the patient's house. It occurred when an attempt was made to test the electrical reactions of her muscles under rather disagreeable circumstances. On previous occasions the mechanical and electrical tests had given negative results. On one such occasion an ice-pack was applied to one of her upper limbs in order to ascertain whether the chilling of the extremity would have the effect of manifesting the myotonic reaction. Mechanical stimulation produced indeed weakly positive

A B C D E F

FIG. 1.

results. On the occasion of the visit to the family's house, an attempt was made to test the electrical reactions under similar conditions. Instead of surrounding the upper limb with ice, it was sprayed with ethyl chloride. The procedure, carried out in the presence of a dozen members of her family, embarrassed her, and she was rather disgusted by the odour of the drug. Upon the application of the faradic current to her arm-biceps, a singular thing happened. A wave of rigidity swept visibly over the upper part of her body beginning at the waist and rapidly involving the shoulders, the upper extremities, the neck and some of the facial muscles. She sat rigid and erect, the head thrown back over the back of the chair, with the upper extremities

extended and semi-abducted. The eyelids were tightly closed and the jaws set. The muscles of her arms and forearms stood out with great prominence, and were of a hard, woody consistency to the touch. But the musculature of the thighs and legs was normally relaxed. She moaned slightly, as if from intense discomfort, and tears came out from between the tightly closed eyelids. In order to ascertain whether she was conscious or not, the faradic current was applied to her arm, and she signified by a louder moan that she felt it. After two or three minutes the rigidity gradually passed away, first in the neck, then in the upper extremities, then in the trunk. The parts attacked first were the last to relax, with the exception of the eyelids, which were still closed. Asked to open them she replied with perfect composure that she would do so as soon as she could, and explained that the eyelids were always last to open in these attacks. She did open them in another minute or so. In the entire procedure there was not the least trace of exaggeration or emotionalism. Her feelings on that occasion, she explained later, were only those of discomfort and embarrassment in the presence of so many members of her family. Questioned respecting the relaxed condition of the muscles of her thighs and legs during the attack, she explained that such was always the case when the attack occurred while she was in a sitting position; but if she happened to be standing the rigidity involved her entire body, including the lower extremities, and then she would fall "like a log."

Apart from these attacks she had no muscular troubles.

There were no other neurological abnormalities in this case.

Case 3.—Sarah E. M., aged 45, weight 223 lb. Married and has one child. Her appearance is very similar to that of her sister Louise and her brother Herbert: she has the same fair complexion, blue-grey eyes and brown hair.

She has never suffered from "nervousness." For a great number of years she suffered from pains in the legs, and they have been weak since she was a young girl, but very much more so of late years. Ever since she can remember, and until a few years ago, she has been subject to the following disability: if she grasped an object quickly she could not retain it in her hand, the fingers would spring back and remain rigid for a minute or so. She was, therefore, compelled to take hold of objects with a certain degree of deliberation.

She has just undergone a major surgical operation, and an examination for myotonia could not be made in her case.

The Border-line Psychosis Group.

This group, consisting of two brothers and a sister, is of interest here mainly on account of its Mendelian phases. A brief account only will, therefore, be given.

The oldest member of this group is Laura C., aged 41. Weight 56 lb. A widow and childless. Of medium stature and build, she has a dark-olive complexion, dark chestnut-coloured hair and deep blue eyes. She has been a

very "nervous" woman all her life. She is subject to attacks of profound depression, alternating with states of irritability, "just like mother." She has, besides, attacks during which her lower limbs are cold and numb, especially at night, irrespective of the surrounding temperature.

She has never had any muscular trouble.

Electrical and mechanical tests of her muscles gave negative results.

The second member of this group is William L., junr., aged 36. Weight 145 lb.; carpenter by trade. In appearance he is very much like his sister Laura —, of medium stature and build, with a dark olive complexion, dark-chestnut-coloured hair and deep blue eyes. He married twice and has two children, one by each wife.

Two or three times a year William has attacks of "nervousness" of about two weeks' duration. During these attacks he is "out of his mind"—does not work, wanders about aimlessly and talks a great deal and quite incoherently, repeating the same sentences over and over again. During a recent attack he appeared at his sister Louise's house—a distance of about five miles —at 3 o'clock in the morning. He shows no tendency to commit violence during these periods of disorientation. In the lucid intervals he is a good, steady workman and a devoted husband and father.

He has never had any muscular trouble, and electrical and mechanical tests of his muscles revealed nothing abnormal.

The third member of this group is Harry L., aged 23. Weight 150 lb. Unmarried and a clerk by profession. In appearance he is like the two preceding members of this group, having the same colour of the skin, eyes and hair.

He suffers from "general nervousness," a perpetual feeling of uneasiness in the presence of people, a sense of inferiority. He is shy and awkward in all things. He has had headaches as long as he can remember. He has refused profitable employment for the last twelve months, being held back by some power for which he cannot account, and attempted suicide in a fit of despondency. "I strive for the higher things in life, but I cannot get a move on myself toward their attainment. I have no push. I cannot put myself forward. This makes me at all times down-hearted and at times despondent. I am just like mother used to be. You can tell by the way I speak the kind of a chap I am." One could indeed to a certain extent. His speech had a peculiarly slow quality, which appeared to be due not to any defect of the motor apparatus of speech, but to one of the mental processes corresponding to it. His responses were hesitant, as if from an over-anxiety to say exactly the right thing while labouring under the conviction that he was about to say exactly the wrong thing.

He has never had any muscular trouble, and electrical and mechanical tests of his muscles showed them to be normal.

The Third Generation.

This generation is represented by ten children, as follows:—

Herbert, of the myotonic group, has two children. Both resemble him in appearance, and the elder, who was examined for myotonia, was found to have it. The other was not examined.

Sarah E. M., of the myotonic group, has one child. In appearance this child resembles the father, who is not a blood-relation of the affected family, and he has neither muscular nor mental trouble.

Louise, of the same group, has five children. Four out of the five are of their mother's physical type and are affected by myotonia. The fifth, a girl, resembles her father, who is not a blood-relation of the family. Like her father, the girl is in every respect normal.

Laura and Harry, of the border-line psychosis group, have no children. William, of the same group, has two. They were not seen by the writer, but according to information furnished by the relations, the children look like their respective mothers—William having been married twice and each of his wives having given birth to one child. Like their mothers, who were not blood-relations of the family, the children have neither muscular nor mental trouble.

The third generation, then, falls into two groups: the normal and the myotonic. Of the five normal persons, two were examined, and one will suffice as an example. It is Estelle (fig. 1, E), the oldest child by the marriage of Louise and Frank W. She is 14 years of age, of a rather slender, athletic build. Like her father, the girl has a light olive complexion, green-blue eyes and red-brown hair, and presents neither muscular nor mental trouble.

The Myotonic Group.

Case 4.—Lorraine L., aged 7, is the elder daughter of Herbert L. She resembles her father in features, and in the colour of her skin, eyes and hair.

The child is well in every respect; her relations have not noticed any muscular abnormality.

Examination showed her movements to be normal. Mechanical and electrical stimulation of her muscles resulted in a normal contraction succeeded by a slow relaxation. The myotonic phenomenon was particularly marked in the right biceps and to a less degree in the other muscles of the same arm. The result of faradic stimulation was in this respect more definite than that of mechanical stimulation.

The tendon reflexes were normal.

In order to avoid repetition, the following may be said respecting the four cases of this group next to be described. All four, the children of Louise W., have certain physical characteristics in common. In appearance they all

resemble their mother, as may be partly judged from the family photograph (fig. 1), in their facial characteristics and in the colour of their skin, their eyes and their hair. The last, however, varies in shade according to age, the hair of the younger members being of a lighter shade than that of the older. Thus the mother's hair is dark brown, while the children's hair varies from a golden brown in the older (Mildred), to a simple light brown in the youngest. The golden quality is said to be due to sunburn. Notwithstanding the difference in shade, however, the essential colour is the same in this group, and is distinctly different from that of the other groups. They all appear to have rather bulky muscles, but judgment in this respect becomes difficult when dealing with very young children.

Case 5.—Mildred W. (fig. 1, C), 12 years of age. She was the first of the series to present herself for examination. She was brought by her mother to the Neurological Division of the Vanderbilt Clinic on August 22, 1921, with the following history:—

The teachers of the public school which she attends complained to the parents that the girl, though sensible and obedient, behaved in a manner which introduced a certain amount of disorder into class discipline. She lacked the necessary promptness of action. She was the last to be on her feet when the order was given for the class to rise. She was the last to comply with the command of the teachers to put the pencils down on the desk, or to close the books. Ordered to recite, she was silent for a number of seconds; yet once she began, she proceeded smoothly. This initial retardation was especially evident in her physical exercises. A repeated command, or one uttered in an angry voice, made matters only worse, she retarded even more. Exhortation being of no avail, the teachers suspected a physical or mental defect and informed the parents.

The mother furnished the following data:—

Mildred is her second child. She was born at term, after a prolonged and difficult labour which was terminated, however, without the aid of forceps. The baby weighed 7 lb. at birth and appeared normal in every respect. She was breast-fed, cut her teeth at 7 months, said "papa" and "mamma" at 10 months and began to walk at 14 months. Her general health in childhood was very good. She had chicken-pox and measles and, at the age of 6, diphtheria without complications. She began to attend school at the age of 5, and she is at present in the 6th Grade, Grammar School, which is the normal grading for her age. She first menstruated a month ago.

Although the child began to walk at the normal period, it was soon noticed by the parents that she stumbled and fell a great deal. Later it was noted that she was reluctant to run about with the other children at play. Urging and scolding on this point having proven to be ineffective, the parents became reconciled to the condition.

Upon being questioned, Mildred stated that her tardiness at the beginning of movements is due neither to an inability to understand the meaning of a

command, nor to lack of desire on her part to fulfil it, but to a rigidity of the musculature involved, which supervenes the moment she attempts the particular movement. As a matter of fact the more anxious she is to carry out the movement promptly the greater is the rigidity which sets in, and the longer, therefore, is the retardation. Thus an angry or a repeated request on the part of the teacher, making her more anxious to comply, has exactly the opposite effect from that which is intended. Yet once the rigidity of the part wears off, she performs the movement without any difficulty. What is true of her movements in compliance with a command, is true also of the movements initiated of her own volition. She has much difficulty in ascending the first flight or two of stairs, but once she has climbed these she can climb the rest without any difficulty. While she is sitting in a chair, her muscles are perfectly lax, but the moment she attempts to rise they become rigid, and the rising movement is, therefore, executed clumsily. While she stands, she feels that her muscles are in a normal condition, but the moment she wishes to walk her muscles stiffen. After walking a few steps, however, the movements become normal. When she closes her eyelids tightly, she has difficulty in opening them for a number of seconds. If she presses her tongue against the palate, she feels it become rigid. The first movements of flexion and extension of the forearm at the elbow, with the hand relaxed, are a little difficult, but the succeeding movements are easy. But if she attempts to perform the same movements with the hand closed in a fist, flexion and extension of the forearm become more and more difficult, until after a few repetitions movement becomes impossible: the forearm remains semiflexed at the elbow, while the fingers half-open, and point in all sorts of directions in a grotesque manner from a contracted palm of the hand.

What is true of movements initiated of her own volition is likewise true of those which occur independently of her will. Thus, when she is suddenly and unexpectedly pushed from behind, she falls to the floor in a rigid mass. If she sneezes, her eyelids remain closed and she cannot open them for a time.

The girl is large, very muscular and powerful-looking. Weight 121 lb. All the subjective symptoms elicited on questioning were found to be true by objective examination, and need not be repeated. The peculiar behaviour of the movements of flexion and extension of the forearm upon the arm, which is apparently anomalous in Thomsen's disease, will be considered in the discussion as elucidating the mechanism of the abnormal muscular action. The reflex behaviour of the muscles was tested in several ways. The girl was made to sneeze (the administration of snuffing tobacco provided an excellent diagnostic agent) and her eyelids remained contracted for thirty seconds, during which she was making strenuous efforts to open them by the action of the frontalis muscle.

When a muscle was tapped with the percussion hammer, it contracted promptly and normally; the marked deviation from the normal being the slowness with which the muscle relaxed after the cessation of the stimulus. The degree of muscular contraction and the length of time taken by the

subsequent process of relaxation were in direct proportion to the strength of the blow and to the number of rapidly repeated blows. The table below gives the approximate number of seconds taken by the particular muscle or group of muscles to relax, after contracting in response to the stimulus of one, two and three moderate blows dealt in rapid succession with the percussion hammer.

	One blow	Two blows	Three blows
Right arm-biceps	10 seconds	15 seconds	20 seconds
Left arm-biceps	15 ,,	25 ,,	30 ,,
Right supinator longus	7 ,,	10 ,,	13 ,,
Left supinator longus	5 ,,	7 ,,	10 ,,
Right anterior forearm muscles ..	7 ,,	10 ,,	13 ,,
Left anterior forearm muscles ..	3 ,,	5 ,,	8 ,,
Right posterior forearm muscles ..	3 ,,	6 ,,	10 ,,
Left posterior forearm muscles ..	3 ,,	6 ,,	10 ,,
Right triceps	7 ,,	10 ,,	15 ,,
Left triceps	10 ,,	13 ,,	17 ,,
Pectorals	4 ,,	6 ,,	10 ,,
Sternomastoids	5 ,,	7 ,,	10 ,,
Posterior leg muscles	5 ,,	7 ,,	10 ,,
Peroneal muscles	5 ,,	7 ,,	10 ,,
Right thenar muscles	7 ,,	10 ,,	12 ,,
Left thenar muscles	7 ,,	10 ,,	12 ,,
Right hypothenar muscles ..	3 ,,	5 ,,	8 ,,
Left hypothenar muscles	3 ,,	5 ,,	8 ,,
Tongue	Not definite	3 ,,	5 ,,

The length of time taken by the muscles to relax after the cessation of the stimulus varied in a striking manner with the season of the year and the general condition of the patient's health. The table above held true for the moderately warm weather early in the autumn and a generally good state of the patient's health. With the onset of colder weather, and during slight indispositions, the relaxation time of the muscles was very much prolonged, in some instances doubled.

Stimulation with a faradic current of moderate strength produced the same effect as striking the muscles with a hammer, and the figures need not be repeated. Erb's classical reaction was not obtained in full.

What was true of a given number of blows of a certain strength was likewise true of a smaller number of blows of greater strength. Thus one strong blow produced the same effect as two or three gentler blows. And the same held good for faradic stimulation.

The superficial reflexes were normal. The radial, ulnar, wrist, supra-patellar and Achillis reflexes could not be obtained, and a slight patellar reflex was obtained only with much difficulty.

The muscular strength, although good throughout, was not so great as one would expect considering the very large size of the muscles. Sensation was normal. The internal organs were apparently healthy. There was a trace of albumin in the urine, which was otherwise normal. The blood Wassermann test, done in order to exclude a possible complicating circumstance, was negative.

The patient was seen a number of times during the late summer, throughout autumn and the beginning of the winter. All the symptoms became exaggerated to an astonishing degree with the onset of cold weather. The movement of rising from a sitting position and the first steps were clumsy late in the summer. In the beginning of the winter she would rise from a sitting position with a sliding and turning movement, as if she had been glued to the chair; her first steps were made with the thighs and knees semiflexed, and it was not until she had walked for two or three minutes that her gait approximated the normal. She began to suffer with pains in her thighs and legs which were so severe that they interfered with sleep.

Case 6.—Edward W. (fig. 1, B), 10 years of age. His birth was difficult but no instruments were used. Development normal. He had otitis media at the age of 6 months, measles at 2 years of age and pertussis immediately after. During the attack of pertussis circumcision was performed on account of some complication. At the age of 3 he developed diphtheria; antitoxin was administered, but post-diphtheritic paralysis of all four extremities occurred, lasting for nine weeks. Recovery was apparently complete.

The boy attends a public school and is quite bright at his studies. No symptoms of any muscular abnormality have been observed either by the family or by the teachers.

Upon examination the movements in response to commands were carried out normally, but mechanical and faradic stimulation of the muscles showed a persistence of the contraction after the cessation of the stimulus. The abnormality was particularly marked in the biceps, the supinator longus and the thenar muscles on both arms. Faradic stimulation was more effective in eliciting the abnormality than mechanical stimulation. The tendon reflexes were normal.

Case 7.—Mabel W. (fig. 1, F), aged 5. Instrumental delivery. Development normal. No diseases of childhood.

For some time it has been noticed that after the child sneezes her eyelids remain closed for a number of seconds, and that she remains hesitant when urged to perform a sudden movement. This is particularly marked when getting off a street car, just as in the case of her grandmother. On such occasions her legs remain "bound" for a time, so that she has to be supported or carried out.

Physical examination revealed the symptoms and signs of Thomsen's disease. When the child was asked to close and open her hand repeatedly each successive movement became more difficult, so that after a few movements the fingers remained extended upon the contracted palm, pointing in different directions. If she persisted, however, the difficulty was soon overcome, and the subsequent movements were normal. The following myogram (fig. 2) shows clearly the behaviour of the anterior muscles of the forearm in the attempt to open and close the hand repeatedly. Made to sneeze, the eyelids remained closed for a number of seconds.

Mechanical and faradic stimulation of the muscles revealed a persistence of the contraction beyond the time during which the stimulus was applied. The phenomenon was especially marked in the arm-biceps, the supinator longus, the muscles of the thenar and hypothenar eminences and the calf muscles on both sides.

In every other respect the child appeared to be quite well and normal.

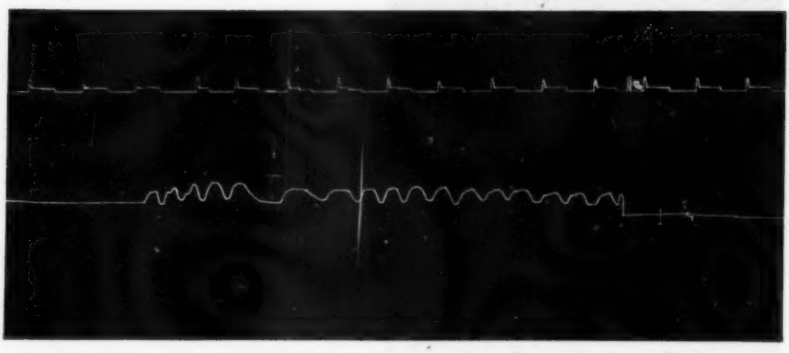


FIG. 2.—(*Case* 7.) Anterior forearm muscles in the attempt to open and close the hand repeatedly.

Case 8.—Nathalie W. (fig. 1, A), 3 years and 6 months of age. Instrumental delivery. Development normal. No symptoms of Thomsen's disease.

Gentle tapping with the percussion hammer and weak faradic stimulation gave indefinite results. Stronger stimulation was not practicable in the case of the young child. The administration of snuff proved to be a valuable diagnostic measure; after sneezing, the child's eyelids remained tightly contracted for some seconds, and then opened very gradually in the course of ninety seconds, the orbicularis standing out with peculiar prominence. The tendon reflexes were normal.

THE MECHANISM OF THE ABNORMAL MUSCULAR ACTION.

This was studied to advantage in the movements of Mildred's (Case 5) upper limb.

With the hand and fingers relaxed, the patient had some slight difficulty in going through the first few movements of flexion and extension of the forearm upon the arm. The first movement was quite normal, the second slightly difficult, the third, fourth, and fifth progressively more difficult, the sixth less difficult, the seventh still less so, the succeeding movements being normal. The myograms reproduced in figs. 3, A and 3, B were taken from the patient's biceps.

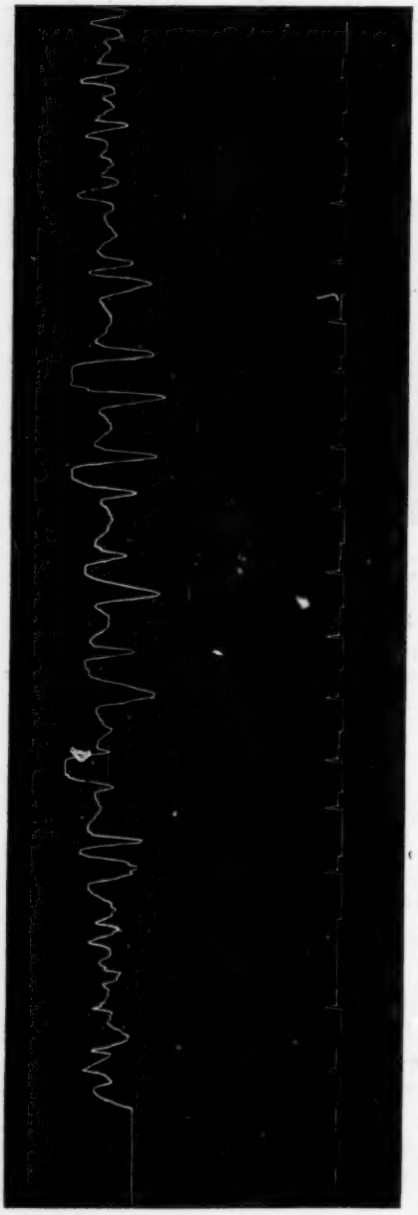


FIG. 3, A.—Mildred W. (*Case* 5). The behaviour of the biceps in the action of flexion and extension of the upper limb at the elbow with the hand relaxed.

When, however, flexion and extension of the forearm at the elbow were performed with the hand closed in a fist, the curve was never completed; the retardation increased until the movement ceased (fig. 3, B). Each succeeding movement was more and more difficult until after four or five repetitions the forearm remained semi-flexed upon the arm, the fingers being opened and extended in different directions upon a contracted palm. The entire musculature of the upper extremity was contracted, the individual muscles standing out prominently.

A somewhat similar instance has been described by Wichmann [44], who considered it "a fluke of Thomsen's disease." Martius and Hansemann [25] have observed an analogous phenomenon in a case of paramyotonia; and Pelz [32] cites a case of Weichmann's, in which a tonic spasm occurred after forced movement.

The seeming discrepancy of this phenomenon with the general tendency of the movements to be-

come normal after a few repetitions throws a good deal of light upon the mechanism of the muscular action in this disease. The facts in connection with this phenomenon will, therefore, be taken up in greater detail.

When the patient's arm biceps was gently tapped with the percussion hammer, the response by a contraction was quite normal. The subsequent relaxation, which in the case of normal muscles follows immediately after the momentary contraction, was in the case of the patient gradual, extending over a number of seconds. If, after the muscle was completely relaxed, it was tapped again, the same phenomenon was repeated. If, however, the muscle was tapped while

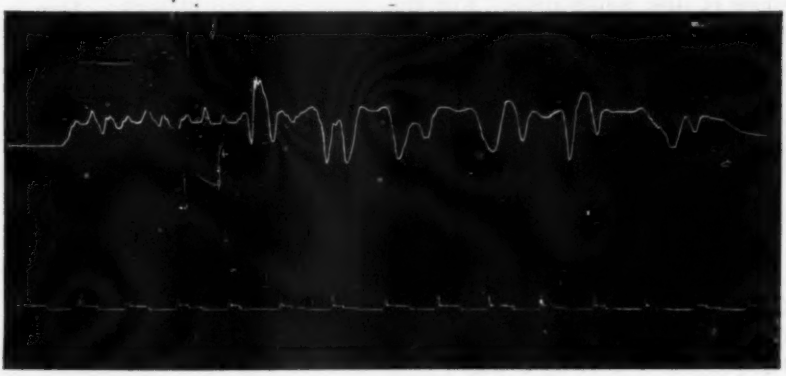


FIG. 3, B.—The same with the hand closed.

it was still contracted, the subsequent response was a seemingly greater contraction. By tapping the muscle, say six or eight times in rapid succession, it became contracted into an irregular, angular mass, of a woody consistency to the touch, and the patient complained of a pulling pain in the bicipital fossa. What happened was a simple summation of the preceding residual contractions. The succeeding relaxation then took a considerably longer time.

When the biceps and the triceps were alternately struck in rapid succession, the biceps did not contract into an irregular ball. After a few blows the forearm remained semiflexed upon the arm and the biceps muscle, although very firm to the touch, retained its regular belly-shape. This muscle was obviously held back from contracting into a ball by the persistent pulling of the opposing triceps.

It made no difference by what stimulus the action of the muscle was evoked, whether by tapping with a hammer, or by an electric current, or by volition or emotion, the resulting abnormal phenomenon was always the same—a persistence of the contraction beyond the duration of the stimulus and, in the case of a stimulus repeated in rapid succession, a simple summation of the residual contractions.

It is not an easy matter, however, to bring a volitional or an emotional stimulus to bear upon any single muscle, as may be done by the tap of a hammer, or the application of a faradic terminal. Unless the forearm is thoroughly supported, a request to contract the biceps, except in the case of a few especially gifted persons, will result inevitably in the contraction of a number of muscles, including some of the antagonists. For this there are two reasons. One is that in the habitual movement of flexion at the elbow, all the muscles passing over the anterior aspect of that joint take part. The other reason is that in order to enable the biceps to exert a measured pull upon the forearm the arm is fixed at the shoulder joint by all the muscles passing over that joint, including the antagonistic triceps.

We shall presently see how these facts furnish a clue to the entire mechanism of the abnormal muscular action in Thomsen's disease in all its varied aspects.

Let this be borne in mind that what is true of the necessity of fixing the shoulder joint in the movements of the forearm upon the arm, is true as well of the necessity of the fixation of any proximal part for the purpose of moving a distal segment to which it is immediately or mediately linked. Thus, in order to make a fist, the elbow and the shoulder joints must be fixed in any position of the upper extremity, except perhaps in the perpendicularly downward position. In order to move the upper part of the trunk, the muscles of the lower part of the trunk are contracted, thus converting a number of the lower vertebræ into a solid column from which the attached muscles can exert a pull upon the upper vertebræ. Since the larger muscles pass over more than one joint, it follows that the contraction of such a muscle may subserve two purposes simultaneously: one, the movement of the distal segment; the other, the fixation of the proximal segment.

When our myotonic patient is requested to make a fist and then to flex and extend the forearm upon the arm, she begins, therefore, these movements with the musculature of the upper extremity already in a state of partial contraction. When a normal person, under similar conditions, flexes the upper limb at the elbow, the extensors, contracted

for the purpose of fixing the forearm at the elbow and the arm at the shoulder, relax in correct proportion to the contraction of the flexors. In the myotonic person, however, the contracted extensors do not relax with sufficient despatch. The force exerted by the flexors in order to raise the mere weight of the forearm must be greater than normal by the amount necessary to overcome the pull of the opposing extensors. This is accomplished by sending a stronger volitional stimulus to the flexors, and the patient may be plainly seen to exert the volitional effort. The resulting greater contraction of the flexors, however, is succeeded by their slower relaxation. In the next succeeding movement of extension, the muscles engaged in that movement are called upon to work against the force of the tightly contracted flexors.

A succession of movements of flexion and extension, brought about by muscles which are already contracted for the purpose of fixing the segments of the limb (the hand being closed in a fist), results, therefore, in the myotonic person, in something more than a simple summation of the residual contractions. We have here a system of mutually aggravating conditions, and the residual contractions of the antagonistic groups of muscles are accumulated in a geometric ratio.

Thus, considering the manner in which the residual contractions are summated in the biceps and triceps in the alternate contractions of these muscles, the greater the amount of residual contraction of the triceps the greater must be the contraction of the biceps in order to move the forearm through a given angle. The subsequent residual contraction of the biceps is greater, therefore, in amount than it was in the case of the triceps. When the triceps is now called upon to extend the forearm, the amount of force which it must exert is greater than that exerted by the biceps in flexing it, and the subsequent residual contraction greater now than at the beginning. The amount of force which the biceps must exert in flexing the forearm the second time must, therefore, be greater than that exerted in flexing it the first time.

The result of the geometric summation of the residual contractions of opposing muscle groups, is that after a few movements of flexion and extension the entire musculature of the limb is contracted to its utmost capacity. Every segment then remains in a position between flexion and extension.

It is almost certain, however, that if the patient could overcome the rigidity and flex and extend the forearm a few more times, the succeeding movements would become easier and finally normal. This is

the case with every other movement of Mildred and with the same movement when performed by her sister Mabel (Case 7). What happens in the particular instance may be likened to the case of a traveller who, having climbed a hill, is so exhausted near its summit that he cannot surmount it and cannot, therefore, get to the other side where travelling is easy.

In view of our ignorance of the ultimate causes of muscle contraction, it would be useless to speculate upon the reasons for the diminution and the final disappearance of the residual contraction of the myotonic muscles upon the repetition of the movement in which they are engaged. Thomsen ascribed the abatement of the rigidity upon repetition of the movement to a concomitant rise in the temperature of the active muscle. Considering the effect of temperature upon chemical processes and upon the phenomena of osmosis and of surface tension, as well as the fact that all conditions of muscular rigidity are lessened under the influence of a higher temperature, Thomsen's assumption may not be far from the truth.

The mechanism of the rapidly accumulating residual contractions of opposing muscle-groups accounts for the sudden falling "like a log" of some myotonic patients under the influence of sudden strong psychic or emotional stimuli. Cases 2 and 5 are examples of such patients. Such instances have been described by Charles Bell [3] as early as 1837, before the disease was recognized as a definite entity. Thomsen speaks of the effect of psychic stimuli upon the myotonic person as follows: "When a psychic impression awakens the muscular cramp, whether it is fright . . . a friendly blow on the shoulder from behind, or when the foot strikes against an unexpected stone, or when a sudden noise reaches the ear, a painful feeling shoots through the entire voluntary musculature, like an electric current. Every affect is exaggerated in the susceptible disposition, fright and anger as well as joy."

The effect of a sudden strong psychic or emotional stimulus is to fix every proximal segment of the body and the limbs preparatory to any possibly desired movement of the distal segments. Throughout the vertebrate and a large part of the invertebrate kingdom, this fixation of the proximal body-segments may be observed in the act of "priming," which precedes the movements of aggression or escape. In man, under normal conditions, the widespread effect of a sudden strong emotional stimulus upon the general musculature of the body is little noticed: the general stiffening is usually of momentary duration; and where the duration is longer the rapidly alternating con-

tractions and relaxations of antagonistic muscles are exactly timed, constituting a perfectly co-ordinated system. Such is not the case in Thomsen's disease. In this disease there occurs, as we have seen, an overlapping of the contractions of alternately acting antagonistic muscles. In the rapid series of such alternating contractions of numerous antagonistic muscles which constitutes the act of "priming" there must occur, therefore, in the myotonic person a rapid accumulation of the residual contractions. The result of such an accumulation is that in a few moments the muscles become contracted to their utmost capacity and the person, no longer able to perform the fine balancing movements necessitated by the erect position, falls "like a log." In the instance of a similar attack described (Case 2), the parts of the patient which were thoroughly supported escaped rigidity. Since the muscles of these parts were not at work at the time, there was no basis for the formation of a series of mutually increasing residual contractions of antagonistic muscle-groups.

It will be remembered that the amount of *residual* contraction is in direct proportion to the degree of contraction; and that the degree of contraction is in direct proportion to the intensity of the stimulus. This explains the reason why in the instance of Case 1 the hand became "bound" only when the act of grasping was accompanied by that of lifting. The stronger stimulus determined to the muscles engaged in the double exertion of lifting and of grasping, made the myotonic condition of those muscles manifest where a weaker stimulus was inadequate.

The mechanism of mutually increasing *residual* contractions of antagonistic muscles differs essentially from Brissaud and Bauer's [6] explanation of the abnormal muscular action by a "synergic contraction of the antagonists." In the light of this mechanism, Jaquet's [18] theory of the irradiation of the nervous impulse to opposed muscle-groups is untenable. Johnson and Marshall's [20] idea of a block in the pyramidal system as the cause of the trouble is inconsistent with the symptomatology of the disease. From these authors' description it does not appear that they found in their cases either the sign of Babinski, or exaggerated deep reflexes, or abnormal associated movements, or a persistent hypertonus of the resting muscles, or any of the signs of interruption of the pyramidal path. Such signs have not indeed been mentioned by any writer as part of Thomsen's disease, nothwithstanding the fact that Thomsen himself thought the disease to be due to a defect of volition. The intactness of the pyramidal

system in this disease is fully attested both by the absence of the signs just mentioned, and by the readiness with which a given set of muscles responds to the impulse of volition. Yet contract as it may, a muscle cannot move the part to which it is attached if that part is held back by an equivalent or by a greater force; and the retardation of movements in Thomsen's disease is not due to any tardiness of the muscles in contracting, but to the resistance offered by the unrelaxed antagonists.

Hoffmann [15] mentions a number of theories brought forward by different observers to explain the singular affection, and there is no need for repeating them here.

The Bearing of Heredity on the Large Musculature associated with Thomsen's Disease.

The distinctive features of the pathological state, as demonstrated by Jacoby [17], Schifferdecker [34], Dejerine and Sottas [8], Pelz [32], Johnson and Marshall [20] and others, are the great thickness of the fibres of the voluntary muscles, the great number of nuclei which are also found within the sarcoplasm and, in some cases, an increase of the interstitial tissue. Jacoby made the interesting statement that "it is obvious that a considerably larger number of embryonic sarcoplasts must have entered into the construction of each individual fibre than is the case in normal development."

It is certain that although Thomsen's disease does occur in persons with a musculature of average size, such an occurrence is quite exceptional. Assuming that the size appeared normal in the cases where no mention is made of it, the number of myotonics with muscles of ordinary bulk must still be quite small. By far the greater number of writers on Thomsen's disease speak of the large size of the musculature of the persons affected by it. Westphal [43] considered the disease to be "a singular congenital anomaly of muscle tone connected with an unusual increase of volume." Mills [26] tried to account for the large size of the muscles by "the frequently repeated, forced exercise."

A study of the family in question furnishes the following facts regarding the association of myotonia with a large musculature:—

The first male, who was not myotonic, had a large musculature; while the first female, who was myotonic, had muscles of the average normal size. Of their six surviving children, three have large and three average-sized muscles. Those with large muscles are myotonic,

while those with muscles of normal size are not. A glance at the respective weights of the six members of the second generation tells the story. The weights are as follows:—

Myotonic group	Non-myotonic group
Sarah, aged 45, weight 223 lb.	Laura, aged 41, weight 156 lb.
Louise, ,, 35, ,, 228 ,,	William, ,, 36, ,, 145 ,,
Herbert, ,, 33, ,, 210 ,,	Harry, ,, 23, ,, 150 ,,

Of the ten members of the third generation, four have no myotonia and their musculature is of normal size; while five who are known to be myotonic show a tendency to a large musculature. Another shows the same tendency, but has not been examined for myotonia. In the case of the younger children, however, it is difficult to form a positive opinion as to the size of the muscles, and one judges largely from general impressions, which may a few years hence prove to have been wrong. But there is no doubt whatever in the case of the oldest myotonic member of the third generation, Mildred (fig. 1, C). She is 12 years of age, has very large muscles and weighs 121 lb.

With the exception, then, of the one child who has not been investigated, it may be said on the whole that those of the descendants who have inherited the first male's large musculature have also inherited the first female's myotonia; while those who have inherited the first female's average-sized musculature, have inherited the first male's normal muscular state.

The last feature assumes somewhat greater significance when the other inherited characters are considered together with the inheritance of the two characters just spoken of. The tabulated inherited characters are as follows: the muscular condition, the size of the muscles, the colour of the eyes, hair and skin, the form of the nose, the facial expression, the mental state and the sex. It must be understood at the outset, however, that conclusions respecting the colour of the eyes and hair drawn from ordinary observation, as was done in the present instance, are not entirely reliable. The writer was assured by so eminent an authority on Mendelism as Professor T. H. Morgan that, with the exception of the colour of the skin, exact colour determinations are made possible only by means of rather complicated tests. In estimating the colour of the hair, allowances must be made for the shade, which varies with age. Nothing has been said in the report of the cases about the form of the nose and the facial expression, because these characters are even more difficult to define with any degree of exactness than is the colour of the eyes and hair.

The shape of the nose in the myotonic members of the family appears in several ways different from that in either the psychotic or the normal group. A single instance will suffice for illustration: the tip of the nose in these myotonic persons is pointed; in the three members of the psychotic group it is rounded. The four types of normal persons have as many different types of noses; Estelle's nose, for example, is of the "humped" variety, and exactly like her father's.

The expression of the face as a single hereditary entity is a good example of that conception of the Mendelian unit character which is so thoroughly condemned by Pearson [30], Conklin [7], Morgan [27], and other experts in Mendelism. A moment's thought must indeed make it plain to anybody that a great number of items, both structural and functional, conspire in the production of a given facial expression. The inheritance of that "unit character" must imply, therefore, the inheritance of all the numerous factors which constitute it.

It is the opinion of the older members of the affected family—and that opinion is largely upheld by photographs—that all the myotonic members have inherited the tip of the nose and the facial expression from the grandfather—the first male; and that the psychotic members have inherited these characteristics from the grandmother—the first female.

In the following table the particular form of the nose will be designated as pointed, rounded or humped; and the different facial expressions as A, B and C.

From this table we gather the following facts:—

(1) That with the exception of *myotonia* and *no myotonia*, the recorded characters of the first male, as well as those of the first female, formed an unbroken chain which was transmitted as a whole, constituting the general appearance and the mental state of the particular individual.

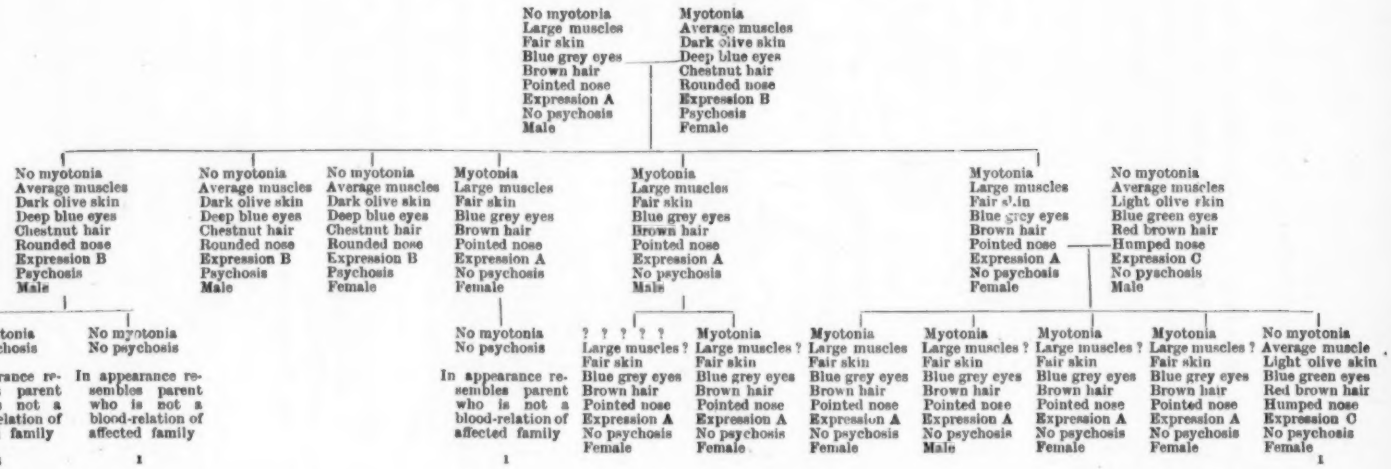
(2) That in some of the offspring the general appearance and the mental state of the first male, in others those of the first female, have proved to be dominant.

(3) That the offspring who have inherited from the first male his general appearance and his normal mental state, have also inherited from the first female the character of myotonia.

(4) That the offspring who have inherited the general appearance and the abnormal mental state of the first female, have also inherited from the first male the normal state of his musculature.

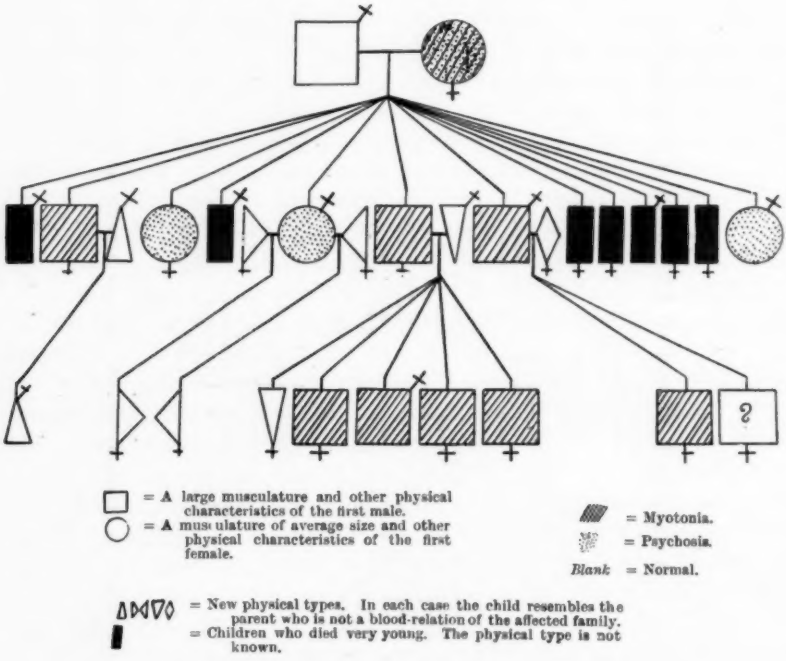
(5) That myotonia is not sex-linked in these cases.

A TABLE OF RECORDED INHERITED CHARACTERS.



[1] An example of the four new types is that of the female at the extreme right. In appearance she is like her father (immediately above) who is not a blood-relation of the family.

The records on myotonia congenita make no mention of the association of any special physical characteristics with the muscular abnormality, with the exception of a large musculature. Since no general inference can be drawn from a single instance, we are for the present justified in the conclusion that *the particular character which offered a ready linkage to the character of myotonia, was that of a large musculature.*


?
= A large musculature and other physical characteristics of the first male.
= A musculature of average size and other physical characteristics of the first female.
= Myotonia.
= Psychosis.
Blank = Normal.
= New physical types. In each case the child resembles the parent who is not a blood-relation of the affected family.
= Children who died very young. The physical type is not known.

Note.—The arrangement is in the order of birth.

FIG. 4.

In the case of the family in question, then, it would appear that some of its members have a large musculature, not because they are myotonic, but because the hereditary factor of a large musculature proved to be a favourable receptor for the hereditary factor of myotonia.

On the Question of Paramyotonia.

Eulenberg [11], Delprat [9], v. Sölder [39], Senator [38], Martius and Hansemann (25) and others, have described cases in which a tardy relaxation of the contracted muscles occurred only in the cold. In some of the cases of the first two authors the muscles remained contracted for long periods of time, in some instances for hours. Erb [10] was of the opinion that cases of this sort belonged to an entirely different category. The affection has received the name of paramyotonia. That there is hardly any justification for setting such cases aside in a different group from Thomsen's disease will appear from the following considerations:—

Quite a number of observers point out the fact that the manifestations of Thomsen's disease are much more apparent during the prevalence of cold weather. Kron [23] goes so far as to include the influence of cold in increasing the prominence of the symptoms among the points which justify a diagnosis of myotonia. In Case 2 of the present series, the myotonic reaction of certain muscles, which was not apparent under ordinary circumstances, was demonstrated after chilling the parts. In Case 5 the myotonic condition of the musculature is exaggerated in a most striking manner in cold weather and by slight general indispositions, such as the menstrual period or an ordinary coryza.

No two of the eight cases of the present series are of the same grade of severity, nor do any two exhibit quite the same manifestations of the affection. In one the tardy relaxation of the muscles occurs only when their contraction has been brought about by a primitive form of stimulus —the so-called emotional or psychic stimuli of fright or anger—and then the myotonic phenomena are most pronounced. In another, almost any stimulus capable of evoking a muscular contraction is sufficient to manifest the myotonic condition of the muscles. In still others only stimuli applied directly over the muscle bring the abnormality to light. The fact that in some of the cases classed under the heading of paramyotonia Erb's classical reaction could not be obtained, means only that a muscular contraction brought about by a stimulus applied from outside directly over the muscle was not sufficient to elicit the myotonic reaction of that muscle. It will be remembered that in Case 8 of the present series such stimuli were ineffective, while the contraction of the orbicularis palpebrarum brought about by the act of sneezing showed beyond a doubt the myotonic condition of that muscle.

Viewing the matter from this standpoint, one is no longer surprised to find that two members of the paramyotonic family described by

Delprat were affected with typical forms of Thomsen's disease. As is the case in every other disease, the manifestations of Thomsen's disease are somewhat different in different persons, and different in the same person under varying conditions. Yet for all its variations the main feature of the disease remains the same—an inherited affection characterized by the failure of the contracted muscles to relax with a sufficient degree of despatch.

Myotonia with Myatrophy. A Mendelian Sub-Lethal Factor. Myotonia Acquisita.

The number of cases in which myotonia is associated with muscular atrophy is very considerable. Nearly all writers agree that the muscular strength of persons affected with Thomsen's disease, in relation to the size of their muscles, is below the normal. The coincidence of myotonia with gross muscular atrophy has been described by Hoffmann [14], Jolly [21], Schultze [37], Bettmann [4], Pelizaeus [31], Batten and Gibb [2], Nonne [29], Fuchs [13], Rossolimo [33], Lannois [24], Noguès and Sirol [28], v. Voss [42], Ramsey Hunt [16], and others. Pelz estimates the occurrence of atrophy in myotonia at 11 to 12 per cent. The fact that atrophied fibres have been found mingled among the greatly hypertrophied ones in cases where there was no gross muscular atrophy, is significant.

After observing the manner in which antagonistic muscles interfered with each other's actions, it occurred to the writer that atrophy might be caused by the repeated pulling and stretching—an actual tearing of muscle-fibres by the antagonistic muscles. The action of the facial muscles, however, would appear to be altogether too weak for such an accident to occur. Yet the facial muscles are involved in the atrophy in a great number of the cases described.

That some nerve elements are involved in the disease in a number of cases might easily be surmised from certain of the subsidiary symptoms. A number of these patients suffer with muscular pains. In the present series Cases 2, 3 and 5 complain of such pains. The diminution or the absence of some of the tendon reflexes is not infrequent in the more pronounced cases of myotonia without any atrophy, and it is very frequent in the cases with atrophy. In the most pronounced case of the present series, Case 5, most of the tendon reflexes are absent or very much diminished, yet there is no discoverable atrophy, and the muscles, when struck with the hammer, respond by normal contractions. The widespread and long-lasting paralysis caused by diphtheria in Cases 2

and 6 (at the ages of 18 and 3 respectively) compels the thought of a special susceptibility of the neural elements in these cases. Of the thirteen members of the second generation, seven died in infancy from obscure causes. Yet the family was not poverty-stricken and its manner of living not unhygienic. Although such an occurrence is not very unusual, yet the fact that the six survivors as well as their children are all affected with one chronic disease or another, naturally impels one to look for a common cause of death and disability in the stricken family.

In the light of the recent discoveries in the field of inheritance, the latter consideration should not appear as altogether far-fetched. Morgan [27] and others have described a Mendelian *lethal* factor in some of the breeds of the Chrysophila fly. In the case of the family under description we have seen that the condition of myotonia has been inherited as an independent factor from the first female; and that it has become dominant, that is to say has become manifest as a muscle abnormality, in those cases where the offspring have inherited a large musculature. But there is nothing in the history of this family, as far as it has been ascertained, to prove that the psychosis of the first female was an entirely independent factor from that of myotonia. The fact that in the records of myotonia congenita we find almost universally the muscular disorder associated immediately or mediately with psychopathies, speaks against the independence of the factor of myotonia from that of the abnormal mental state of the first female in this series. And this conjecture is rather corroborated by the fact that a certain number of the myotonics in this family, although free from psychopathy, are not free from neuropathies. After a careful consideration of the facts in connexion with this family, the suspicion has been forced upon the writer that myotonia congenita is caused primarily not by an inherited abnormality of muscular structure or function, but by an inherited sublethal factor which exerts an injurious action upon the neuro-muscular system. In seven cases the injurious action of this hypothetical agent was sufficient to determine the balance in favour of death. In other instances the existence of this agent is manifested in myotonia with atrophy of individual muscle fibrils, or of entire muscles and muscle-groups. In still others it causes myotonia, with muscular pains and a diminution of the tendon reflexes, with or without muscular atrophy. In others still, especially in cases where the musculature is not congenitally of large volume, the muscular system is spared, and the action of the inherited injurious agent is upon the highest cerebral structures.

Such a conception of the disease might help to explain not only the singular co-existence of psychoses with the muscular disorder either in different members of the same family or in the same person, but the occurrence of the temporary and acquired forms of the disease as well. If myotonia congenita is caused by an inherited abnormal content of the body fluids, then a temporary myotonia might be caused by a temporary alteration of the contents of the body fluids of a certain kind. Such a temporary alteration of the body-fluids must have occurred in the cases described by Talma [40] with an acute febrile onset and severe gastro-enteric disturbances; and by Schultze [36] in connection with gastric dilatation, associated with the symptoms and signs of tetany. The same principle might be applied to the cases where myotonia has occurred in the course of severe disturbances of the central nervous system, such as the case of brain tumour described by Bremer and Carson [5]; of myotonia associated with athetosis described by Kaiser [22], and of myotonia occurring in connection with syringomyelia, mentioned by v. Frankl-Hochwart [12] and by Schlessinger [35].

A Psychological Concomitant of Thomsen's Disease.

It will appear from the history taken in connection with Case 2 that the myotonic mother of four myotonic children, and herself the daughter of a myotonic mother, was reluctant to admit that she suffered from any muscular disorder. As a matter of fact she strenuously denied the existence of the disorder in any member of her family, and this denial was maintained for weeks in the face of numerous facts to the contrary.

Such an attitude of mind appears to be a pretty constant concomitant of the muscular disorder, and is mentioned by a number of writers. Jendrassik [19], in his able summary of the affection, mentions the fact that "the patients seek to conceal their infirmity by all sorts of artifices." Thomsen himself must have been thoroughly aware of this attitude in his own case when he said: "There is an active psychic factor involved, namely, the fear of ridicule. As soon as the feeling arrives that those about will discern and observe the disability, the symptoms become aggravated in the highest degree." In the present case of the mother of the myotonic children there was, in addition to the desire to conceal a lifelong disability that is so thoroughly disguised by an appearance of perfect health and strength, another inhibitory

factor. It was the wish to suppress the consciousness of a responsibility of having transmitted her infirmity to future generations, innocent as she certainly was of any wrong motive at the time when the responsibility was taken.

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A CONTRIBUTION TO THE ANATOMY OF SPINA BIFIDA.

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INTRODUCTION.

THE purpose of this paper is to emphasize certain features in the minute structure of cases of spina bifida which have a direct bearing on details of operative procedure, and on prognosis as regards nervous function after and apart from operation.

Recent medical literature contains few accurate descriptions of specific cases of rachischisis, and the discussion and diagrams in the average surgical treatise are imperfect in detail and often misleading. Since Virchow, Lebedeff and v. Recklinghausen in the eighties, first called attention to the embryological basis of the defect, very little new work has been done, and it appears that this early work has been largely lost sight of. Surgeons have depended upon operative findings which are necessarily incomplete, and pathologists have left these deformities severely alone. It is true that the study of anomalies in many instances is not a fruitful one. To the study of this particular group of abnormalities, however, much practical value attaches, as a large proportion of the less severe types demand surgical relief. The number of cases here reported is small, and the records in some are necessarily incomplete, but material of this nature is difficult to obtain, and especially so in the milder cases round which surgical interest centres.

Before passing to the discussion of individual cases it seems advisable to recall briefly the normal development of the structures which are defective, and the general morphology of the types of defect encountered.

Development of Central Nervous System and Vertebral Column.

The central nervous system first appears as a thickening of the surface ectoderm along the mid-dorsal line of the embryo, the medullary

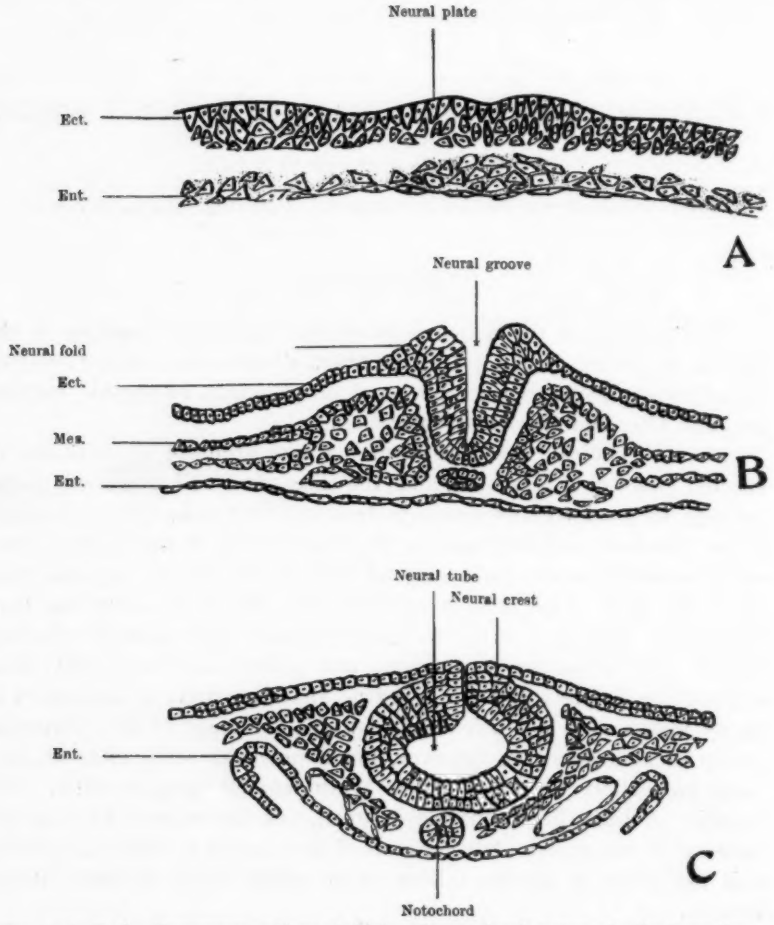

Fig. 1, A, B, C.—Transverse sections of chick embryos, showing stages in the formation of the neural tube.

plate (fig. 1, A). The edges of this plate rise, turn toward the mid-line and finally meet and fuse, forming a closed tube (fig. 1, B, C). Fusion is segmental in character; it takes place first in the cervical region, and

progresses backward and forward, being delayed longest in the cephalic and caudal segments (fig. 3). Ultimately the closed neural tube sinks beneath the surface, mesodermal structures interpose themselves and the neural ectoderm continues its growth independently of the integument. In the regions last closed there remain for some time minute openings, the neuropore at the anterior extremity and the caudopore at the posterior, through which the central canal communicates with the exterior. Ultimately these openings also become closed.

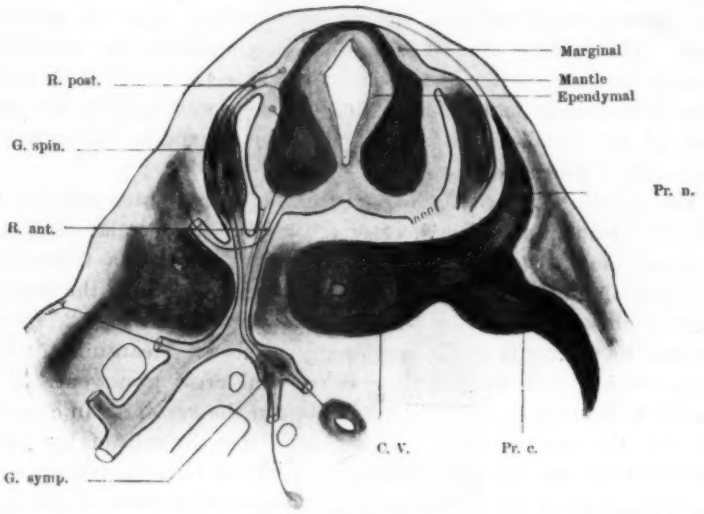

FIG. 2.—Schematic. Left side modified from *Prentiss and Arey*, showing the origin of the spinal ganglia and the spinal nerve roots. Right side represented as though sectioned through vertebral body, showing the early stage of vertebral development with the origin of the neural arch.

In the meantime, even before the medullary folds have completely fused, an increase in size of the cephalic portion of the folds becomes apparent and one can differentiate the brain from the spinal cord (fig. 3). It is not necessary here to deal with the complex further development of the cerebral vesicles, but attention must be confined to that of the cord. In its separation from the surface ectoderm there persists for a time at the mid-line a chain of cells, the neural crest (fig. 1, C), having the characteristics of the cells of the neural tube proper. From this chain are formed the posterior root ganglia (fig. 2, *G. spin.*) and the

ganglia of the sympathetic system (fig. 2, *G. symp.*), as well as the nerve cells found in various viscera.

The further development of the spinal portion of the neural tube consists in the rapid proliferation and specialization of its cells resulting in a differentiation into three zones, outer, middle and inner, distinguished by the grouping and ultimate fate of their cell contents. Certain of the cells become neuroblasts, the forerunners of neurons; certain others, also ectodermal, become supporting glial cells. The inner zone (fig. 2, *Ependymal*) undergoes but little increase; it consists of glial cells only, which form the ependymal lining of the small persistent central canal and the narrow surrounding layer of gelatinous tissue. The middle zone (fig. 2, *Mantle*), containing the neuroblasts, becomes the grey matter of the cord; the outer zone (fig. 2, *Marginal*) becomes the white matter, consisting of the processes from the neuroblasts of the middle zone and of the spinal ganglia, supported in a meshwork of neuroglia.

The middle zone rather early becomes differentiated into an alar, posterior lamina, and a basal, anterior lamina. In the alar lamina are developed the structures of the posterior horn. In the basal lamina are developed the motor nerve-cells of the anterior horn, and the emerging fibres of these pass out as the anterior nerve roots (fig. 2, *R. ant.*) between the segments of the developing vertebræ. Meantime the spinal ganglia which have formed from the neural crest pass ventrally and laterally until they lie in the spaces between the vertebræ, in close contact with the anterior nerve root fibres. From the cells of the ganglia processes pass into the outer zone of the cord and form the posterior roots (fig. 2, *R. post.*) of the spinal nerves. Fibres from these ascend in the posterior columns; others form synapses about the cells of the posterior horn. These relations are shown diagrammatically in the left side of fig. 2, representing a cross section of a 10-mm. human embryo.

While these changes are occurring within the neural tube, mesendermal structures come into relation with it, and form a delicate sheath, which later becomes separated into three layers, pia, arachnoid, and dura mater. Anteriorly, the vertebral column is developing with the notochord, which is shown in fig. 1, A and B, as its point of departure.

The right half of fig. 2 shows diagrammatically an early stage in vertebral development. Surrounding the notochord is the rudiment of the body of the vertebra (*C. V.*), with the beginning of a costal process (*Pr. c.*) and a second process (*Pr. n.*) directed dorsalward and partly enclosing the spinal medulla. This is the neural process from which

develop the laminæ and the spinous processes. The laminar processes grow out from the neural process toward the mid-line of the embryo, surrounding the spinal cord and forming the spinal canal. In a fœtus

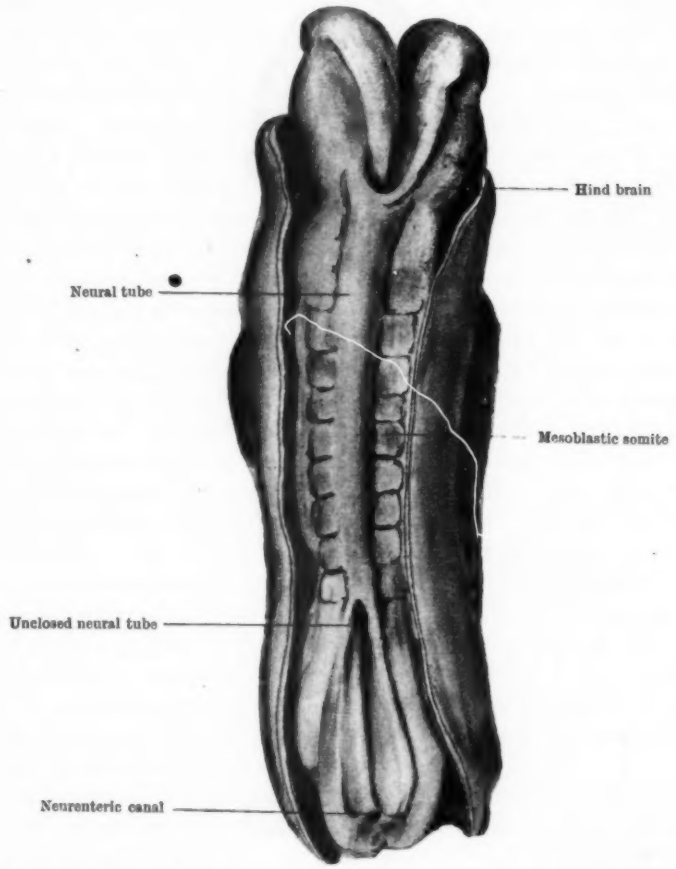

FIG. 3.—Human embryo of 2·11 mm., showing closure of neural tube, and early stage in differentiation of cerebral region. (After Keibell and Mall.)

of 33 mm., about nine weeks, they extend well out towards the mid-dorsal line, and are united across this by a membrane of connective tissue. In one of 50 mm., about the eleventh week, they are united so as to form a canal similar to the adult spinal canal, and small spinous

processes are developed upon them. The completion of the spinal canal takes place earlier in the thoracic than in the cervical and lumbar regions.

FIG. 4.—Human embryo, aged 3 months, showing the spinal cord extending to tip of coccyx. (After Keibell and Mall.)

During this period, as is shown in fig. 4, the cord extends throughout the whole length of the spinal canal, and the nerve roots and spinal ganglia formed in each segment take up a position between the bases of the neural arches, in the future position of the intervertebral fora-

mina. Growth of the neural tube and of the vertebræ progresses at equal rate until the third month, and up to this time the nerve roots continue to pass out of the canal perpendicularly to the long axis of the cord. Fig. 5, A, shows a diagrammatic representation of the relative positions of neural and of vertebral segments at this stage. In the further growth of the embryo, however, the growth of the neural tube is outstripped by that of the vertebral column, and as it is anchored above by its attachment to the medulla it remains high in the canal, terminating at birth at the level of the third lumbar vertebra (fig. 5, B). This is usually referred to as "the upward migration of the cord." At the tip of the coccyx, the extremity of the cord remains for a long time connected with the surface (fig. 5, A), and this connection pulls the end of the cord and the pial sheath into the slender filum terminale (fig. 5, B). It will be necessary to describe this in greater detail later, as it has direct bearing on the defects which occur at this region of the neural canal. The spinal nerves, having a fixed relation to the intervertebral foramina, are carried away from the cord segments with which they are connected by the growth of the vertebræ. Their roots elongate to compensate for the unequal growth, so that while those from the upper segments continue to pass out almost horizontally, those from the lower segments descend more and more within the canal as one passes downwards. At birth a cauda equina is found similar to that in the adult. Fig. 5, B, shows schematically the relation of cord, spinal ganglia and nerve roots as they are found in the full-term fœtus; it does not differ materially from that in the adult. It should be mentioned that in making fig. 5 the skeletal basis of the diagram was drawn to scale from an actual dissection in a seven months' fœtus. For purposes of comparison this skeletal scheme was used for all the diagrams in this figure, as the particular change under consideration seemed better brought out in this way.

The formation of the filum terminale and its relation to the coccygeal segments of the cord has a direct bearing on the structure of lumbosacral spina bifida as it differs from spina bifida in other areas of the neural tube, and must therefore be discussed in slightly greater detail. The coccygeal segments, with the exception of the first, are rudimentary. Their cells do not differentiate beyond the embryonic stage of a layer of glia cells surrounding a central canal. The last coccygeal segment remains attached to the surface ectoderm, and with the increased growth of the vertebræ this undifferentiated area becomes drawn out into a slender thread of glia in which for a long time there

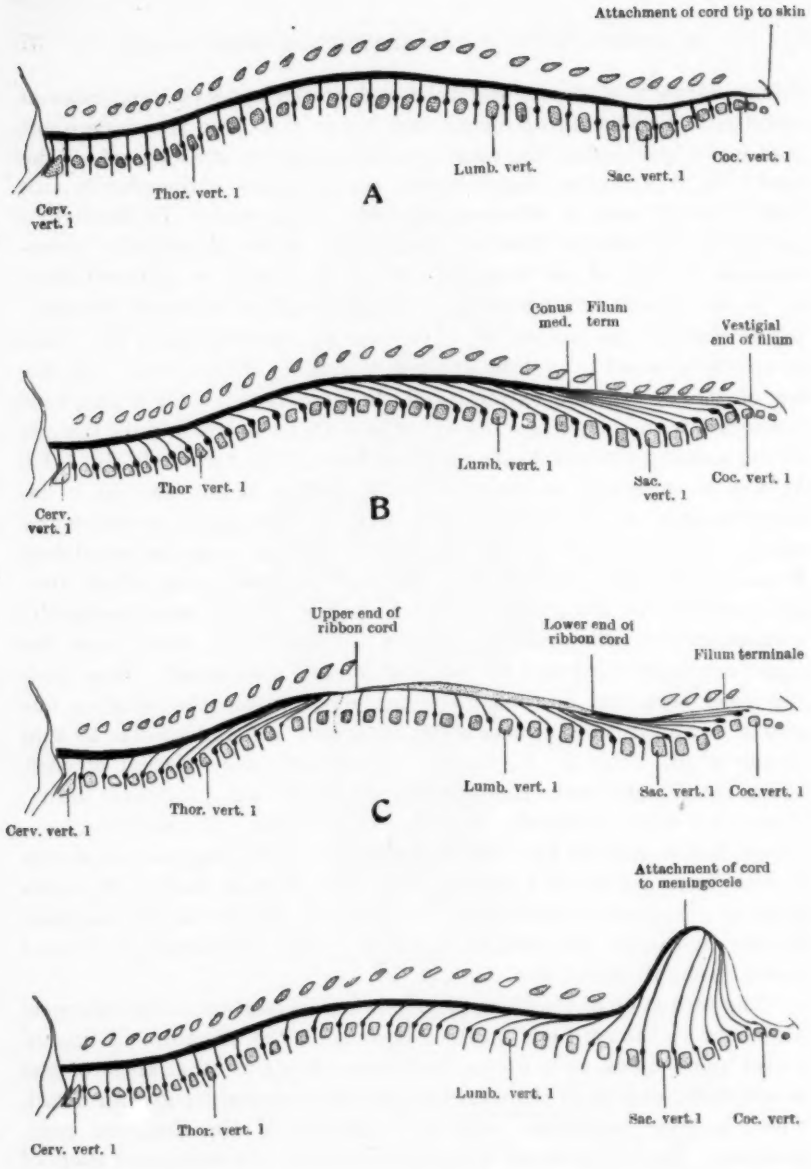

FIG. 5, A, B, C, D.—Diagrammatic representation of migration of cord and relations of nerve roots: A, in 3 months' fœtus; B, in fœtus at term; C, in Case I, myelocele; D, in Case III, myelomeningocele. The skeletal basis of all the figures was taken from a dissection of the spinal column of a 7 months' fœtus.

is a persistent central canal. It remains attached to skin by its tip, and higher up in the rudimentary coccygeal part of the spinal canal it is separated from the skin only by imperfectly differentiated meningeal layers, and by a band of fibrous tissue which alone represents the vestigial coccygeal laminæ (fig. 5, B). Even in the full-term fœtus nervous elements can still be found in it. The filum terminale as low down as it remains glial represents, therefore, the lower four coccygeal (tail) segments, which have become drawn out so that they stretch from the tip of the coccyx to the level of the first coccygeal cord segment which lies at the level of the third lumbar vertebra. The normal adherence of the end of the cord to the skin surface, and its persistent rudimentary state in this region, have a direct effect in producing one variety of meningomyelocele found in this region of the spine.

Morphological Basis of Spina Bifida.

It is not within the scope of this paper to enter into the underlying causes, probably of a bio-chemical nature, which determine the occurrence of spina bifida and of other basic developmental defects. It is necessary merely to point out the morphological factors which are concerned in this particular class of cases.

Apparently the mechanism of closure of the medullary folds is one of the most delicately adjusted of developmental processes, for anomalies are of fairly frequent occurrence both in man and in other vertebrates. In chick embryos which have been improperly incubated it is a common experience of the embryologist to find a number in which the folds have partly or entirely failed to unite in the usual time sequence with other organs. Usually very young embryos only present this deformity, probably because the older individuals die from the unfavourable conditions which have produced the defect. Other laboratory embryos, as opossums, pigs, &c., present the defect more rarely, doubtless because of the normal conditions of their existence, as these embryos are fixed and prepared in utero, and not artificially incubated.

It will be seen that any interference with the closure of the medullary folds will, of itself, cause a corresponding interference with the development of the neural arch of the vertebra forming around that region of the cord. Any defect, however slight, involving the medullary tube proper, is associated with defect of the vertebral neural canal. Such medullary tube defect has morphologically a wide range of possibilities, from mere delay in the closure of the caudopore with a consequent delay in the development of the membranes of the cord in this region and of the integument covering them, to a complete lack of the infolding

of the medullary plates, with or without differentiation of the neural ectoderm forming the plates. In certain cases the defect in the medullary tube has been so slight or so evanescent that in the fully developed embryo no trace of defect remains in the cord itself, but its existence is revealed by an imperfection of membranes associated with a corresponding defect in the vertebral canal. In still other cases, one finds no such definite evidence of an original medullary tube defect, the anomaly consisting merely of a failure in the fusion of the vertebral spines or of the laminæ. More rarely laminæ are partly or wholly absent. This is probably also dependent in a proportion of cases on medullary tube defect, for nervous symptoms are not infrequent. Reference will be made to this later in the discussion of the types of spina bifida encountered in actual specimens.

It will be seen that all these variations of the deformity may occur throughout the entire length of the medullary tube, or may be limited in extent. The development of the cephalic extremity of the tube and of the cranium is so divergent from that of the spinal cord that no attempt will be made in this paper to discuss defects involving the brain (cranio-rachischisis). It must be remembered, however, that defective development of one part of the neural tube is prone to be associated with defective formation of other parts, and cephalic abnormalities are frequently found with spinal. Fusion of the spinal part of the medullary folds tends to be normally later in the cephalic and in the caudal ends of the embryo than in the mid-thoracic regions, and local defects are more apt to occur at these points; but the fusion is segmental in character and segments at any region may fail to unite without necessarily impeding the union of segments above or below. The rudimentary character and morphological peculiarities of the coccygeal segments (filum terminale) already alluded to may be responsible for the great number of defects occurring in this region.

It is particularly necessary to remember the time sequence of the structures which participate in the defect. Normally the entire neural tube is closed at the end of the third week; it is then the full length of the embryo. Normally the vertebral neural arches from the first cervical to the third or fourth sacral are closed at 50 mm. (eleventh week); the arches below the fourth sacral are normally rudimentary. The defect, whether it be a failure of closure of the medullary groove, or an adherence of meningeal layers to skin, cannot occur after the vertebral arches are closed; and at this period of growth and indeed for a short time thereafter (third month), the vertebral column and

the spinal cord are increasing in size *pari passu*, so that each cord segment lies in line with the corresponding vertebral segment. However, should defect occur, the general development of the remainder of the embryo may go on unaltered except by mere mechanical hindrance at the point of defect. It is also possible that growth in size and histological changes may occur even in the defective area, as though it were morphologically perfect. On the other hand, if the morphological defect is great, or has been produced at a more "critical period" in the development, no growth nor differentiatiou of tissues may occur, and in such cases the mechanical factor determining other local changes may be greatly increased.

It is necessary to emphasize these points because it has been customary to describe rachischisis as though the parts involved bore the same relations to their surroundings at the time of the origin of the defect as they would normally bear in the same locality in the fully developed fœtus.

Types of Spina Bifida.

If the entire length of the spinal canal remains open the condition is known as *rachischisis totalis;* if a considerable number of segments are involved, but not all, it is known as *rachischisis partialis;* if a small number are involved, the remainder being normal, *rachischisis restricta.* If the neural groove has remained open the rachischisis is said to be *complete;* if it has closed, it is *incomplete.* Rachischisis totalis is practically always complete in its entire extent, but there appear to be a few cases in which the lower segments of the cord have closed and are covered by meningeal layers, though skin and vertebræ are defective. In rachischisis partialis part of the defect is complete, but in practically all cases part will be found to be incomplete. In rachischisis restricta the majority of cases are incomplete, a few complete, and a considerable number are incomplete in some of the segments and complete in others. The further classification is rendered difficult by the merging of one type into the other due to the varying degrees of causative defect; it is perhaps most satisfactory if it is made upon an embryological basis.

The varieties fall into three classes from an embryological point of view: (1) Those in which the gross defect is limited to mesoblastic structures. (2) Those in which the defect is mainly mesoblastic, but in which there is a slight ectodermal defect. (3) Those in which the gross defect is ectodermal and the mesoblastic condition is a mere

accompaniment. Probably in the more severe cases of Class 1, and in all cases of Class 2, the causative factor is primarily ectodermal, but the imperfection of this has been obscured by its relatively normal aftergrowth.

Class 1.—Mesoblastic defect (rachischisis incompleta restricta).

(*A*) *Spina Bifida Occulta.*

The simplest forms of this type are those in which the spines of one or more vertebræ are bifid either at their tips or to the bases of the spines. The spines of the upper cervical vertebræ are normally bifid in Europeans, but one frequently finds in the dissecting room a seventh cervical with bifid spine, and more rarely other vertebræ. These cases never give rise to symptoms, and are probably never associated with nervous defect.

A more serious anomaly is that in which the laminæ (neural arches) are incompletely formed or entirely lacking. In the normal spinal column the fourth sacral sometimes, and the fifth sacral and coccygeal vertebræ always, present this defect, and it is not infrequently encountered in the higher sacral and the lower lumbar vertebræ, without any associated lesion of meninges or cord. More rarely the absence or imperfection of the laminæ is accompanied by an adhesion between meninges and integument, abnormal fat development, or peculiarities of the epidermal structures, as hypertrichosis. Without such external evidence of anomaly the condition is not ordinarily discovered except in the course of a chance X-ray examination, or of anatomical dissection. In a certain proportion of cases, however, the adhesions or the overgrowth of fatty tissue cause pressure symptoms, and anæsthesia, paræsthesia, or paresis call the surgeon's attention to the condition, and operation for the relief of pressure reveals the true nature of affairs. A certain number of these cases probably represent small meningoceles of Class 1 (B) which have become obliterated in early life.

(*B*) *Meningocele.*

Here the vertebræ are defective, and in addition there is present a cystic protrusion of the meninges. Careful examination of cases of this type shows that the relationship of the various meningeal layers presents wide variations. In some differentiation of the integument has proceeded normally, and the cystic tumour is covered by well-formed skin. In the majority, however, the integument is thin, covered

by imperfect epidermis and adherent to the presenting meninges. To this imperfect skin the term "parchment" is fittingly applied; it is poorly vascularized and of low vitality. On opening into the sac and examining its walls one may find a variety of conditions. (1) The sac wall may be composed of fused dura and arachnoid, or of these two layers in close proximity but not fused, forming a distended single sac representing the subarachnoid space, in the bottom of which the cord courses down covered by pia in the normal manner. (2) The dura and the arachnoid may be separated by a collection of fluid, the tumour consisting of an outer dural and an inner arachnoid sac, the pia and cord being normal. (3) The outer layer of pia may be likewise distended, forming a third, usually much smaller sac, within which the cord lies. (4) In any one of these forms the cord may be lifted up by the fluid round it, and may course through the middle of the cyst, presenting, however, no obvious abnormality. This condition, however, does not seem to be well authenticated.

Class 2.—Mesoblastic defect with slight epiblastic defect: (rachischisis incompleta restricta).

(*A*) *Myelo-meningocele.*

Here we find a meningocele in which the neural tube has closed but has remained in contact with the surface ectoderm in a small part of its extent, the result of delayed closure usually near the caudopore. The cord is drawn by adhesions to the surface of the sac, and is attached by a greater or less portion of its length to the sac wall. The nerve roots may pass down from its ventral surface to reach their foramina, or may be caught in the adhesions and course down over the surface of the sac. These cases are always covered by parchment skin, but by the microscope integumentary structures may be demonstrated lying dorsal to the neural tube. This variety is probably confined to lumbo-sacral rachischisis, and is the result of the peculiarity of the development of the coccygeal segments already noted; it is, however, often confused with more severe types in which some cord segments have not closed, and many cases described in this class more properly belong to Class 3 (A).

(*B*) *Hydro-myelo-meningocele.*

In certain cases in which the neural tube has closed, either with or without a persistent adherence to the surface ectoderm, as was described above, the central canal of the cord becomes enormously distended by fluid, and within a meningeal sac of any of these types

a medullary sac may be found, the wall of which is formed of thinned nervous tissue, from which more or less perfect nerve roots pass. This form is not infrequently encountered, and is entitled to separate mention because of the importance of differentiating it from the pure meningocele which it resembles clinically. It represents only an exaggerated form of the concomitant hydro- and syringo-myelia which are so frequent in the more severe grades of rachischisis.

Class 3.—Gross epiblastic defect with accompanying mesoblastic defect (rachischisis completa).

(*A*) *Myelocele* (*Rachischisis Completa Restricta*).

Here two or three segments of the medullary folds have remained open and the neural ectoderm lies exposed on the surface of the body as a ribbon of delicate tissue down the mid-dorsal line. On either side the meninges are attached to the edges of the medullary ribbon, and form a zone of parchment skin which passes in turn into normal skin. In certain cases no collection of fluid occurs, but in the majority the meningeal layers become filled with fluid as in pure meningoceles, and the open neural ribbon is stretched over the surface of a tense sac. Cases of this type occur in the cervical region, very rarely in the thoracic, but often in the lumbo-sacral region. In the cervical and thoracic regions they are easily differentiated, but in the lumbo-sacral they are apt to be obscured by the growth of surface ectoderm over the lower part of the neural ribbon. The lower coccygeal segments, functionless in man, never develop beyond the simple neural tube of the embryonic state. The last coccygeal segment normally remains attached to the skin. The tendency of all these segments is towards atrophy rather than growth, while the growth of skin ectoderm is as active as elsewhere in the body. If the upper coccygeal segments do not close, the few neural cells present in them tend to become atrophic and overgrown by skin, and this part of the neural tube is prevented from elongating into the filum terminale. The adhesions to skin so formed mechanically drag down the sacral segments and involve them in the defect. In the lumbo-sacral variety also, probably as a result of the adhesions to skin, fluid is especially apt to collect in large quantity, and its pressure within the meningeal sac may be so great as to draw the normal cord above the open segments down out of its canal and into the sac. Thus a normal cord may appear to end in the middle of the sac wall, and the open medullary groove segments below may be covered by inflammatory exudate or by overgrown integument so that

the significance of cord attachment is entirely overlooked. Careful study will probably result in placing many of the cases which have formerly been placed in Class 2 (A)—rachischisis incompleta—in this class with other complete defects.

With these, as in other cases of cord involvement, hydromyelia and syringomyelia are often associated.

It is customary to refer to the cases of this type in which the meninges are filled with fluid as cystic myeloceles, but while this term has some descriptive value it does not denote any class distinction.

(*B*) *Myelocele* (*Rachischisis Completa Partialis or Totalis*).

These cases do not differ from those in Class 3 (A), except in the extent of the defect, which involves a very large number or all of the neural segments. Because of the extent of the defect there is never an accumulation of fluid in the severer cases. The neural tube lies flattened out in the groove formed by the undeveloped vertebral laminæ upon the surface of the exposed vertebral bodies. The meningeal layers are developed beneath it and pass laterally into a zone of parchment skin which blends with the normal skin. In the cases of total defect, where there has been no abnormal adherence of the cord to the skin over the coccyx, the ribbon cord may migrate upward as in the normally developed cord, and here the lower sacral vertebræ may continue their development, without interference by the neural defect. Total neural lesion may therefore occur without total vertebral defect. This is important because of its bearing on the problems presented by the restricted lesions of the same class.

In both the types just mentioned the medullary tissue may present wide variations in the extent to which the differentiation of its cells has occurred. In some instances the condition remains embryonic, and no trace of the adult medullary structures is to be found; in others the cord substance has developed as though closure of the folds had been accomplished, and the nerve cells and roots can be easily distinguished.

Statistics of the percentage occurrence of spina bifida in its various manifestations are difficult to collect. From observation in the anatomical laboratory it appears that mere vertebral defect is of fairly frequent occurrence. Various forms of meningocele come frequently to the attention of the surgeon, but are infrequently reported, so that no accurate idea of their frequency can be formed. The cases with marked medullary involvement are often born dead, or succumb shortly

to infection. As they are not remediable, they attract but little interest on the part of the obstetrician.

Surgical interest centres about the cases of spina bifida restricta, since it is in these cases that operative interference is feasible. Here, however, while more case records are available, their imperfect nature and the varied use of descriptive nomenclature makes accurate classification a matter of extreme difficulty. This is especially true of those of Class 2, in which there is involvement of the cord.

Before going further it will be advisable to discuss the few cases here studied in detail, and to point out the difficulties of recognizing the types from operation or gross dissections only.

Discussion of Cases.

Method of preparation and study of specimen.—The material studied is partly operative and partly pathological museum specimens. The conditions under which it was obtained made certain features of the accurate study difficult. In the three operative cases (Cases III, IV, VII) it was the writer's good fortune to assist at the operation and in the care of the patients, so that the observations on these were carried out as a continuous first-hand study. In each case drawings were made from the actual specimens, enlarged to scale, and wherever any matter of personal interpretation of the condition modifies the diagrams it is clearly indicated in the description. It will be obvious that certain features of a preserved specimen can be brought out only by personal observation.

In making the microscopic study of the specimens, blocks of tissue of 2 to 3 mm. thickness were cut, embedded in celloidin, and stained by the following methods: (1) toluidin blue; (2) iron hæmatoxylin; (3) hæmatoxylin-eosin. In one or two cases other methods were tried, but as they were not fruitful they were abandoned. All the sections from each block were stained and examined, and the interpretation of certain features in the individual sections was frequently the result of this study. In certain cases where the condition was obscure additional sections were made above and below the original blocks, but detailed description of these is not given. The sections photographed and described are those which appear to throw most light on the anatomical and clinical aspects of the cases. All the photographs were made with a $\frac{3}{4}$ in. objective and reduced to the same scale, so that comparison of their size could be made. They were re-touched with indian ink with constant reference to the slide from which they were made, in order to indicate myelination and nerve cells.

Case I.

Myelocele—spina bifida completa partialis, of Class 3 (B). Specimen No. 1109, Surgical Pathology Museum.

The specimen was received as part of a pathological collection which came into the department of Surgical Pathology of the University of Texas, and no history could be obtained. The preservation was not all that could be desired, and no care had been taken to protect the myelocele from injury in transportation. The body was in good condition, however, except for the more delicate neurological examinations of the brain. The body was that of a negro female fœtus, length 24 cm. from vertex to coccyx. External appearance is shown in fig. 6. Limbs and trunk were well developed in form and musculature. External genitalia and anus normal. Head is hydrocephalic, circumference 41 cm. (occipito-frontal). Face and oral cavity normal. Spina bifida completa extends from level of eighth thoracic vertebra to that of the upper margin of sacrum.

Dissection.—On opening the ventral body wall a diaphragmatic hernia is seen, the greater part of the abdominal contents occupying the left thoracic cavity. The right side of diaphragm is normally developed; the left side presents a widely open pleuro-peritoneal hiatus, through which the whole of the stomach, small intestine, appendix, the first part of colon, spleen, and left lobe of liver protrude into left chest. The heart and pericardium are normal except that they are pushed to the right of the mid-line by the herniated viscera. Right lung is normal in shape, atelectatic, smaller than normal on account of pressure: left lung is very small, about one-fourth normal size and flattened. Thymus is displaced toward the right, but otherwise normal. Examination of the abdomen shows it to be occupied by the right lobe of liver, which is normal except for a distortion in shape due to the herniation of its left lobe and to the abnormal position of the other viscera, and by the descending colon and a large convoluted sigmoid, which occupy their normal positions. The adrenals and the genito-urinary system are normal.

Microscopic examination of the organs was not made, as they gave no sign of structural abnormality.

Skeleton.—Maceration for slight anomalies was not done because of the desire to keep the specimen for demonstration purposes. So far as could be determined without maceration, the skeletal system is normal excepting that the calvaria is typically hydrocephalic, its sutures very wide, and the bones thin and soft. The base of skull and the cervical and upper seven dorsal vertebræ are normal. The lower five dorsal and all the lumbar vertebræ present large flaring laminæ which are curved with the convexity anterior, so as to present on the dorsal surface a wide shallow ditch. The prominences of these laminæ are clearly distinguishable beneath the thin parchment skin of the region (fig. 7). Ossification centres are normal in site and size, in the bodies and laminæ. The sacrum is normal.

Nervous system.—Accurate examination of the brain was impossible because

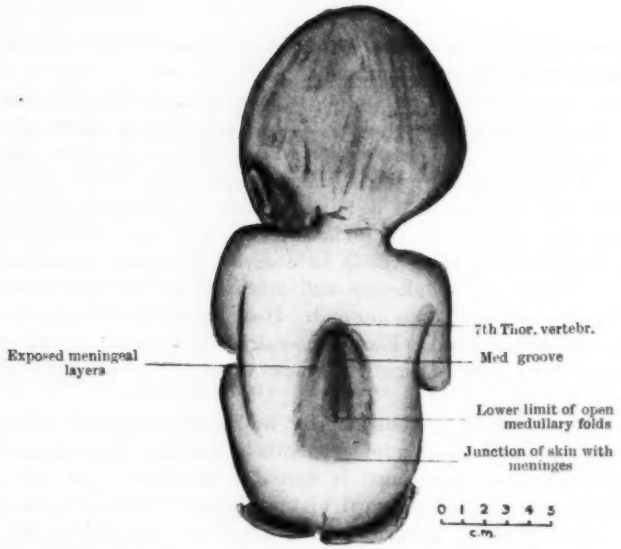

FIG. 6.—Case I, myelocele. External appearance of specimen before dissection.

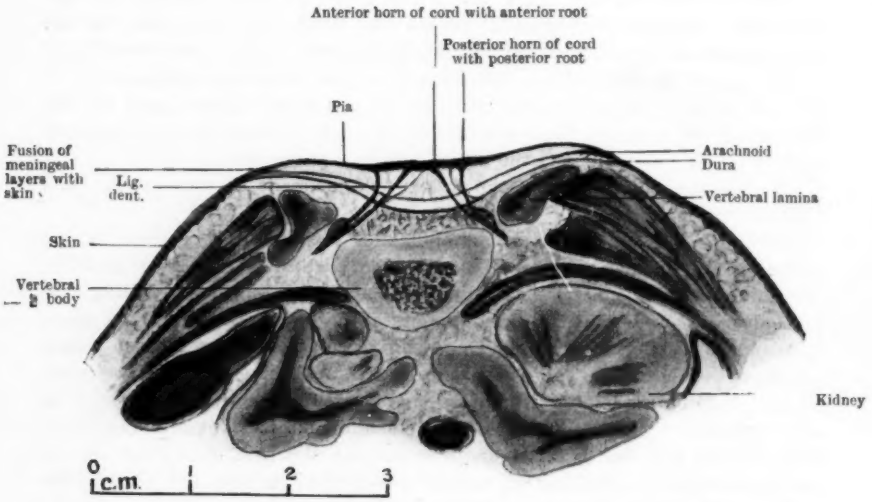

FIG. 7.—Case I, myelocele. Cross section through region of twelfth thoracic segments of the cord.

of the imperfect preservation of this portion of the central nervous system. The lateral ventricles are greatly distended with fluid and the cerebral cortex is thinned to a layer varying from 4 or 5 mm. to the thinness of tissue paper. The choroid plexuses of the lateral ventricles are large, but present no other apparent abnormality. The cerebellum is poorly preserved and appears to

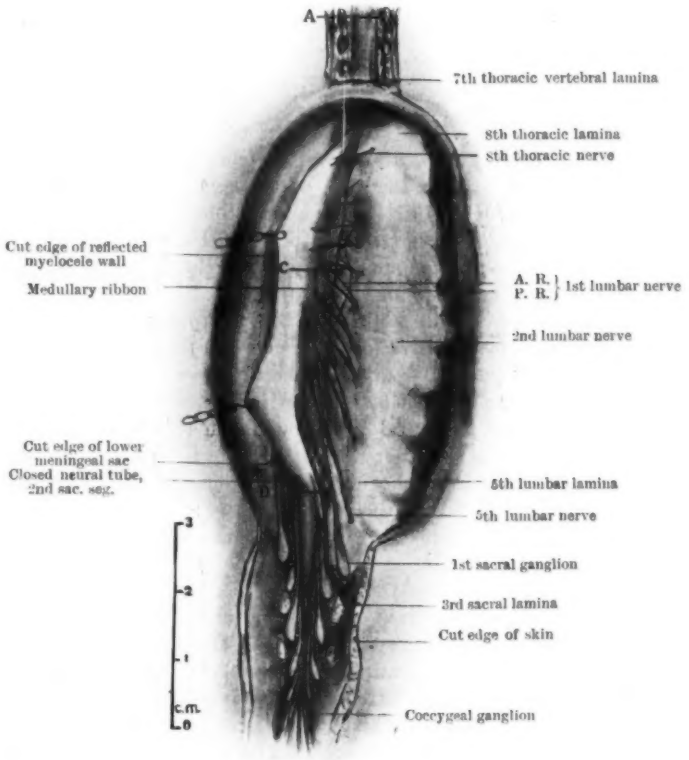

FIG. 8.—Case I. Dissection of myelocele, by reflection of lateral wall and opening the spinal canal above and below the lesion. Levels of the microscopical sections indicated by letters A, B, C, D.

be represented by a mass of loose hæmorrhagic and very vascular connective tissue, with a small amount of nervous tissue at its base, apparently representing the peduncles. The mesencephalon, pons and medulla are macroscopically normal.

The spinal canal was opened from the foramen magnum to the level of the

seventh thoracic vertebra, i.e., the last normal vertebra. The meninges in this region are normal. On exposing the cord it is found to be superficially normal from the medulla oblongata to the level of the sixth thoracic vertebra; but the portion lying on the body of the seventh thoracic vertebra is small, soft and membranous, and terminates by passing under the seventh neural arch to blend with the myelocele below.

The arrangement of the nerve-roots from this whole region of cord is peculiar. The first two cervical pairs pass out almost horizontally; those below incline more and more *upward* in the canal, as is shown diagrammatically in fig. 5, C, so that the roots which pass through the first thoracic foramina come from the cord which lies in relation to the fifth thoracic vertebra. All the roots to this level are large and apparently normal except for their upward direction. At the level of the sixth thoracic vertebra the roots are very delicate, and it is not possible to trace them all, but attenuated fibres from this region appear to enter the second, third, fourth, and fifth foramina (fig. 5, C). From the membranous portion of cord lying on the seventh thoracic vertebra delicate strands pass to the sixth foramina, and possibly also to the seventh, though these may arise from the open cord below.

It is necessary here again to direct attention to figs. 5, A and B, illustrating the normal upward migration of the cord in the spinal canal. In this specimen the seventh thoracic segment of the cord was prevented from moving upward by adherence to the myelocele below. This portion of cord, therefore, represents the segment of neural tube infolded in this body segment of the embryo, and its roots pass out horizontally as they were originally laid down. They are attenuated because the normal development was hindered by the adhesions and by traction, as the length of the spinal canal above them increased. Similarly the upper cervical segments maintained their normal relationships by virtue of their attachment to the brain stem, and their roots pass out horizontally as is usual. If all the medullary tube had developed equally between these two fixed points, the preponderant growth of the vertebral canal should have resulted in an equal stretching of the whole length of the cord, the nerve-roots continuing to pass out horizontally. We find, however, that the lower portion of cord is membranous, and its small nerve-roots show that it has fallen far short of attaining its normal growth; moreover, being largely composed of connective tissue (membrane), it has apparently been much less easily stretched than the higher portions, and has remained almost stationary while the better developed higher segments have been pulled down to its level. A greater descent of the lower cervical segments would be expected, but the inequality of growth of the cervical vertebræ and cervical cord in this specimen is less than the inequality in the thoracic region.

As will be seen later in the description of the myelocele, the nerve-roots below the level of the eighth segment of the cord are also affected by the fixed relations of this cord segment to its vertebral segment, but as the caudal extremity of the cord is not fixed, the cord migration is all upward, and the nerve-roots are carried downward to their foramina, though not to such a great extent as in a normal canal. (See fig. 5, C.)

Myelocele.—In reading the description of the myelocele, it is necessary that constant reference be made to the accompanying diagrams. These were made from the actual specimen and dissections: fig. 6 was drawn life-size and reduced, fig. 7 and fig. 8 enlarged to scale and reduced.

Dissection of the myelocele.—The arch of the seventh thoracic vertebra and the tissues and skin covering it are, as already mentioned, normal in character. At the lower border of this arch, however, as shown in fig. 6, the skin dips down over it and becomes merged in the parchment skin of the myelocele. From the level of the eighth thoracic to the upper margin of the first sacral vertebra lies a translucent membrane of parchment skin, which merges below and laterally at a distance of 10 mm. from the mid-line, into normal skin. Down the middle of this (fig. 6, *Med. groove*) lies a ribbon of soft friable tissue, which passes above into the neural canal of the seventh thoracic vertebra where it is continued into the spinal cord. Below, at the level of the fourth lumbar vertebra, it sinks under the glistening parchment, and passes beneath to enter the spinal canal in the sacrum. This velvety ribbon represents the open medullary tube, and its structure will be examined more carefully later.

On cutting through the parchment near its junction with skin laterally, it is found to be composed of an inseparable fusion of the three meningeal layers of the myelocele with the integument. The epithelium of the integument is here very thin, but presents its normal stratification. Passing toward the mid-line a point is reached where the parchment can be separated into its component layers, and at this point all trace of epithelial covering is lost. The relations of the meningeal layers can best be seen in a cross-section through the middle of the myelocele shown in fig. 7. The most superficial of these layers, viz., the pia, is found to be attached to the medullary ribbon. Anterior to this is a definite arachnoid, and still deeper a thick dura. These are in close contact and are joined by delicate adhesions, which become closer as the lateral edge of the parchment is reached. The line of fusion of the three meningeal layers with skin corresponds closely with the outermost edges of the exposed vertebral laminæ. When an incision is made medial to this line of fusion and the pia is reflected, the medullary ribbon is lifted with it, revealing the condition shown in fig. 8. Posterior nerve-roots are seen to emerge from the lateral edge of the ribbon, and anterior roots more medially. Between the radicles the denticulations of the ligamentum denticulatum pass from the pia to the dura; but a few of these, as shown in fig. 7 (*lig. dent.*), pass medially to the anterior roots. The nerve roots pass through the sub-arachnoid space and into the intervertebral foramina, each carrying with it a sheath of dura and arachnoid in the normal manner. Those from the eighth and ninth segments are very delicate, and on these rudimentary posterior root ganglia are found, but in the lower segments the roots and ganglia are more nearly normal in size. The position of the ganglia is normal with reference to the intervertebral foramina. The roots from the upper four involved segments (thoracic 7, 8, 9 and 10) pass out directly to their foramina, without descent

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in the canal, in the manner shown in fig. 8, and diagrammatically in fig. 5, C. The roots from lower segments incline downwards before emerging, and finally those from the lowest segments pass under the closed meningeal sheath of the lower part of the myelocele already seen in fig. 6, at the level of the fourth lumbar vertebra. On dissection (fig. 8), this meningeal sheath is found to be composed of the three fused meningeal layers, which are adherent for a distance of about one millimetre to each other and to the cord. Almost immediately they become separated into their component parts and lose their adherence to the cord, which is closed from this point down. The cord as it passes under the meningeal covering is flattened, but otherwise normal in appearance, and the nerves surrounding it form a typical cauda equina. As will be expected from a study of the diagram in fig. 5, C, the conus is lower in the canal than normal, and the cord terminates at the level of the third sacral vertebra. Except for this the cord and membranes, which at the level of first sacral vertebra become covered by skin, are quite natural after they enter the sacral canal.

Microscopical examination.—Sections were made of cerebellum, pons and medulla, and at various levels of the cord. The fixation of the brain was not sufficiently good to warrant detailed study. The cerebellum has a fairly well-formed corpus dentatum, and the folia, which are few in number, present a definite cortical layer. The pons contains transverse fibres and lemniscus, both myelinated. Cells of the nuclei pontis are not differentiated. In the oblongata the inferior olivary nucleus is well developed, and the medial lemniscus, the emerging fibres of the sixth and seventh nerves, and entering fibres of the vestibular nerve are myelinated and occupy their normal positions. In all the sections there is a looseness of the tissue and a paucity of fibres and cells even where the general structure is most nearly normal; many small areas occur in which the neuroglial meshes are filled with fluid, and in other parts there is an appearance of œdema of the cells. There are many cells which do not appear to be differentiated into supporting and nerve elements; some perhaps represent neuroblasts.

In studying the sections of the cord it will be necessary to refer to the undissected specimen (fig. 6), and to fig. 8 in which the levels of the sections are indicated, and to recall that a "segment" of the cord is numerically determined by the relationships of its nerve roots, and not by its position in the spinal canal. In this case, as had already been seen, the nerve roots behave in a most irregular manner, and it is only by tracing the connections of the section of cord studied that its segmental position can be determined.

Section A (fig. 9, A).—Level of fifth thoracic vertebral segment (first thoracic segment of cord), above lesion. Sections show a normal central canal lined by an ependymal layer. Cells of the anterior horn of grey matter are well formed and their distribution corresponds with that of normal cord of first thoracic segment.

Cells of the posterior horn, difficult to distinguish even in normal cords, cannot be definitely differentiated. It is probable that a small group of them

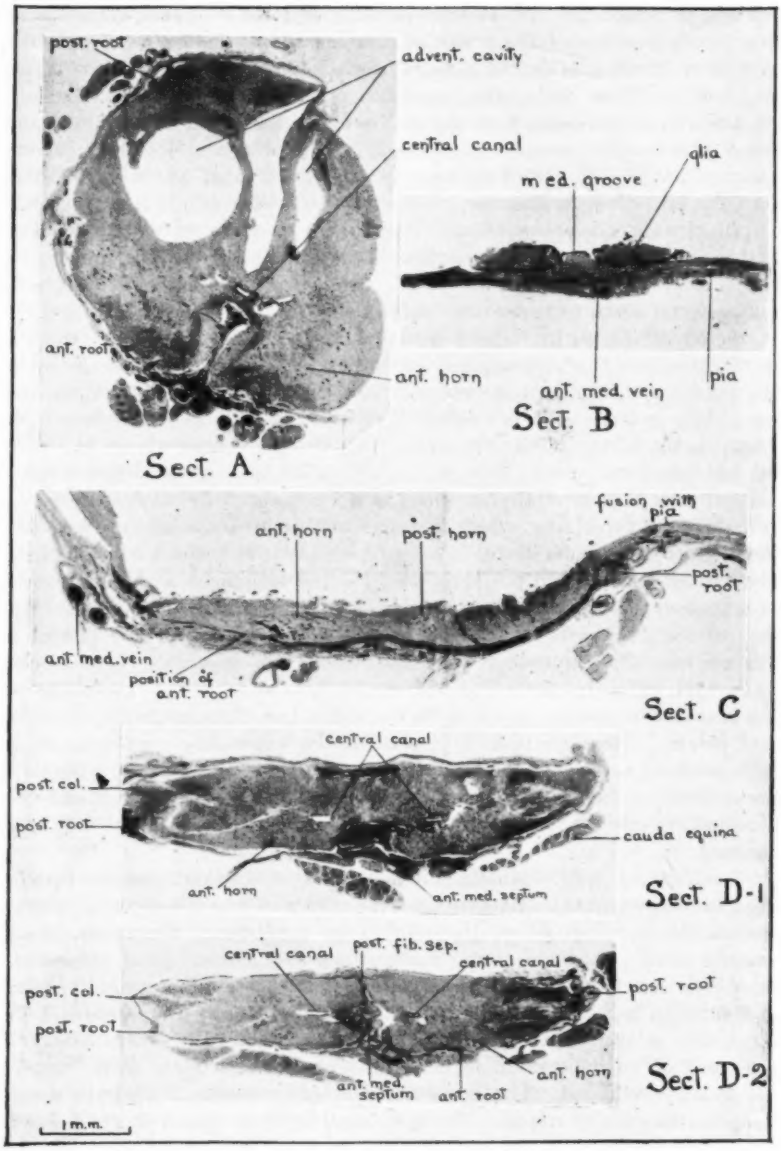


FIG. 9.—Case I, myelocele. Photomicrographs of sections at the levels indicated in fig. 8.

can be made out in the region indicated in the photograph. The posterior portions of the cord on each side are partially replaced by spaces which occupy roughly the position of the posterior columns, the ascending fibres of which have been interrupted in their course by the imperfect development of the cord below. These and similar spaces in other sections to be described are not artefacts, as is evident from the good preservation of the surrounding structures. The ventral cerebro-spinal tract is normal in size and position, and non-myelinated. This tract normally becomes myelinated late in intra-uterine life. No other long tracts can be distinguished. The antero-lateral fasciculi proprii of each side are myelinated; and there are some other scattered myelinated fibres which may be also regarded as association fibres. The surrounding area is composed of neuroglia and of non-myelinated nerve fibres. The anterior and posterior nerve roots are myelinated and occupy their normal position.

Section B (fig. 9, B).—Upper limit of myelocele, level of eighth thoracic vertebra, eighth thoracic segment of cord. At this situation, as shown in the photograph, the cord is represented by a layer of poorly differentiated tissue, two or three cells in thickness (*med. groove*), the open medullary folds. (Compare fig. 1, A). These cells are prolonged for a short distance lateral to the mid-line, but no continuous cell layer can be followed between them and the epithelial surface of the adjoining skin; apparently it has been destroyed in handling the specimen. On either side of this open medullary groove is a small mass of irregular tissue (*glia*) composed of nerve fibres and neuroglia. The tissues beneath are poorly formed pia and arachnoid, and small vessels from these layers penetrate the glial masses; laterally they fuse and pass into the corium. No differentiated nerve cells can be found in any portion of this section. The growth of ascending tracts has apparently been blocked below this region by the adherence of the membrane in the myelocele, but the lateral glial masses undoubtedly contain a few fibres ascending from the cord below. These are in turn blocked at the upper limit of the myelocele with resulting absence of the posterior columns noted in Section A. Similarly the descending tracts are blocked at the upper limit of the defect and only those which are formed in the cord below this level are to be found in lower sections.

Section C (fig. 9, C).—Middle of myelocele, level of twelfth thoracic vertebra (first lumbar segment). At this level the ribbon of medullary tissue shows a remarkable degree of differentiation into its usual fœtal characters. Large anterior horn cells lie near the median line, and a small group of posterior horn cells lateral to them. Small anterior and posterior nerve roots emerge and enter in relation to these cell groups. They are non-myelinated. The substantia gelatinosa is well developed. The remainder of the ribbon is composed of an indiscriminate mass of neuroglia and nerve fibres, none of which are myelinated. The nerve fibres noted in Section B evidently ascend from the cells in this region. The ependymal layer is destroyed, but a depression corresponding with the central canal is found at the median line. The posterior surface is composed of glial tissue and unmyelinated fibres traversed

by delicate fibrils of connective tissue coming from the pia and containing capillary vessels. This glial layer extends laterally for a considerable distance, and is probably augmented by fibres from the tracts ascending from below. Anterior to the medullary ribbon the pia lies in contact with the nervous layer; it is thicker than is normal and contains many vessels and some leucocytes. In it lie bundles of nerve fibres, some of which appear never to join the cord but to be lost in the meningeal tissue. Sections from the lower part of the ribbon cord show the same structure, but the nervous tissue is broken up by many minute blood-vessels, and a delicate vascular plexus extends over the whole dorsal surface from one lateral pial margin to the other.

Where the ribbon cord closes and passes under the meningeal layers, serial sections were made in an effort to find the transition stages. The nervous tissue in the upper of these sections is so obscured by penetrating capillaries that little information can be gained from them. In the upper sections the anterior medial septum sends two lateral trabeculæ, which pass laterally; at the end of each there is found a slightly elongated ependyma-lined cavity. It has not been possible to trace the ependymal cells to the surface of the cord in any of the sections. At a slightly lower level the fibrous septa disappear, but the central canal remains double.

Section D-1 (fig. 9—D-1).—The level of this section indicated on fig. 8 is that of the fifth lumbar vertebra, and the position of the nerve roots show that it represents the second sacral segment of the cord. The cord is flattened antero-posteriorly; the central canal is double. Anterior horn cells are well developed; posterior horn cells cannot be distinguished. A small posterior column is present and is myelinated. The anterior and posterior nerve roots are myelinated. The cord contains little else that is recognizable; it is œdematous and broken up by fine vessels. The nerve roots of the cauda equina are disposed round it; those from the ribbon cord above are non-myelinated.

Section D-2.—Level of the third sacral segment, one millimetre below Section D-1. The central canal is still double at this level. Little change has occurred except that between this section and the preceding an adventitious septum of fibrous tissue has extended inward from the posterior pial sheath, and has here met and fused with the anterior median septum, completely bisecting the cord. Otherwise the structure is as before. In sections slightly below this level the fibrous septum once more disappears and the central canal is gradually lost on one side, so that the lower segments (fourth and fifth sacral) of the cord contain but one central canal which is placed slightly laterally.

Various explanations of this have suggested themselves to me. The simplest, and therefore perhaps the most probable, is that the mesoblast-forming pia which is seen in the upper portion of the myelocele slightly elevated in the mid-line under the open medullary groove, has here likewise been abnormally elevated to a sufficient extent to cause bifurcation of the closing medullary tube. The mesoblast does not, however, come into relation

with the medullary plates in the normal embryo until these are already closed, but where one structure departs from the normal associated structures follow suit. Moreover, if the closure of the folds were markedly delayed in its relation to other processes, it is feasible that mesoblast would follow the time sequence of other mesoblastic development, and not that of ectoderm, i.e., medullary folds. A double central canal is not a very infrequent anomaly in cords with defects other than spina bifida.

General Discussion of Case I.

Attention is especially directed to four features in this case, viz. :—

(1) The influence of the inequality of growth of cord and vertebræ, and the adherence of cord, producing abnormal direction of nerve roots and abnormal position of cord segments in the canal.

(2) The formation of spinal ganglia and nerve roots in segments in which closure of the tube has not occurred.

(3) The absence of histological differentiation in certain of the involved segments, and the normal histogenesis in other segments which are morphologically defective.

(4) The imperfect development of segments above the lesion due to mechanical hindrance.

Case II.

Myelo-encephalocele—rachischisis completa totalis of Class 3 (B).

Specimen No. 1133, University of Texas Pathological Museum.

No complete account of the state of this specimen will be given in the present communication, but certain points in the spinal part of the defect are of value in the interpretation of the other cases under consideration. To these the description will be limited.

Description.—This specimen belongs to the general class of anencephalic monsters, of the type in which there is posterior cleft of the calvaria and spinal column. The mouth and nose are normal, the eyes bulge in the manner characteristic of this type of monstrosity; the forehead is low. The ears are normal in shape, but are situated close to the shoulders, and the chin is drawn down upon the sternum. This position is frequent in anencephalic monsters and indicates the absence or imperfect development of the cervical region, which is a usual accompaniment of the cranial and spinal defect. The general appearance of the body is otherwise normal, and the age about seven (intra-uterine) months.

The specimen shows posterior cranioschisis with protrusion of an imperfectly formed brain enclosed in a pia-arachnoid sheath; the dura covers the base of the skull and extends over the edge of the defect to blend with the skin of the anterior part of the head. The mass of brain tissue extends caudalwards and overlaps the upper part of the bifid spinal canal. Examination of the upper part of the spinal column shows that all the cervical vertebræ

are lacking, and the upper two thoracic vertebræ are either lacking or abortive, as are the cord segments corresponding to these. No attempt has been made at the present time to study the other defects of the cervical body segments. All the ten thoracic vertebræ which are present are cleft; the spinous processes and the laminæ are normal in size, but flare outwards as do those in the affected area in Case I. Examination of the thoracic region shows that ten ribs are present, articulating normally with the thoracic vertebræ; and a cursory examination of the contents of the body cavities reveals nothing abnormal. The upper four lumbar vertebræ are flaring; the fifth has an incomplete arch, which is bridged by a fibrous band. The sacral vertebræ are defective in the spines only. The open vertebral groove is covered by meningeal layers from the base of the skull to the level of the fourth lumbar vertebra. At this level the meninges form a closed tube and pass into a zone of imperfect parchment skin, which blends at the level of the fibrous arch of the fifth lumbar vertebra with skin which is in all respects normal.

A ribbon cord similar to that described in Case I extends from the brain above to the level of the first lumbar vertebra below. Here it passes into a normal filum terminale which is prolonged under the meningeal layers into the sacral canal. The cord in a fœtus of this age (seven months) should end at the level of the third lumbar vertebra. The slightly higher level assumed by this cord is apparently due to defective growth of its segments; it is greatly exaggerated in appearance in the undissected specimen because of the disproportion of the spinal column owing to absence of cervical segments. It is important to note that the entire cord is cleft; the coccygeal nerve arises, as do the nerves proximal to it, from a ribbon of medullary tissue. The lower nerve roots are grouped about the ribbon cord from which they arise, and pass under the meninges at the level of the fourth lumbar vertebra. Here the meningeal layers form a closed tube which passes under parchment skin as described above.

Discussion.—The features of this case which have a bearing on anatomical characteristics of spina bifida restricta are the only ones to which attention is now called.

(1) The "upward migration" of a cord all the segments of which have failed to close.

This appears to be due to the absence of any abnormal adhesions between neural tube and surface ectoderm in this particular case. The formation of the filum terminale indicates that the adherence of the last coccygeal segment (rudimentary) has been normal.

(2) The formation of the lower vertebral segments, which has been carried on to a considerable extent after the upward migration of the corresponding open cord segments. The vertebral laminæ should be fused in the eleventh week, while the migration of the cord does not commence until after the twelfth week. In the lumbar and sacral

regions, however, the completion of the vertebral arches is later than in the thoracic. In this case development progressed as soon as the ribbon cord slipped out of the way. This shows to some extent in Case I, but less strikingly because the complete cord defect in Case I does not extend below the second sacral segment, the segments below this being closed. In Case II, the entire neural tube is open, including the first coccygeal segment, i.e., the last segment which attains adult development in man. The fifth lumbar vertebra has, however, developed a fairly normal arch and the sacral vertebræ are deficient in spinous processes only.

The meninges attached to the lower segments of the open cord have been carried upward by the ascending cord, and the surface ectoderm has developed into normal skin over those vertebræ which possess reasonably normal arches, i.e., as high as the fifth lumbar.

These points will be found to throw light on certain obscure features of cases with defects restricted to the lumbo-sacral region.

Case III.

Cystic myelocele—rachischisis completa restricta of Class 3 (A).

History.—M. E., female, aged three months, John Sealy Hospital.

Family history negative as regards physical defects. This, the first child of this family, has been weakly since birth, and has had constant digestive disturbances. She appears to be normally developed except for a lumbar "meningocele." Five days before admission to Sealy Hospital she had a febrile attack, which terminated three days later, when the upper part of the meningocele ruptured. Pre-operative condition: Examination showed that there was a meningocele occupying the lower lumbar and upper sacral region, covered by typical parchment skin partially collapsed and ulcerated, of a diameter of about one and a half inches. A minute opening was present at its upper part, not in the mid-line, and from this cerebrospinal fluid flowed freely. There was no visible sign of nervous elements on the parchment surface, and the opening did not appear to be a central canal. There was, however, evidence that the condition was not confined to the membranes, as the legs were partially paralysed and there was incontinence of urine and fæces. In a position of rest the legs were kept extended at hip and knee, and no movements of the feet were observed. The thighs were flexed feebly when the baby was disturbed. At the time of admission there was diarrhœa, but careful dressing and attention to cleanliness caused great improvement in the condition of the rectum and in the ulcerated surface of the meningocele. Any handling of the child, and especially touching the sac, produced evacuation of the bowels and bladder. Complete collapse of the sac occurred from time to time, and at these times the child was restless and distressed. The flow of cerebrospinal

fluid remained constant. Operation by Dr. J. E. Thompson, July 8, 1919, under ether anæsthesia. From the start the baby took the anæsthetic badly and artificial respiration had to be resorted to before the commencement of the operation. After this preliminary trouble, however, the respiration, though weak, was regular, and the heart fairly strong. A transverse incision was made and the sac opened. The filum terminale and a pair of nerve filaments were found to be spread over the lower extremity of its inner wall and these were removed with this portion of sac wall. Attached to the middle of the sac was the termination of the cord with its nerve trunks running down across the

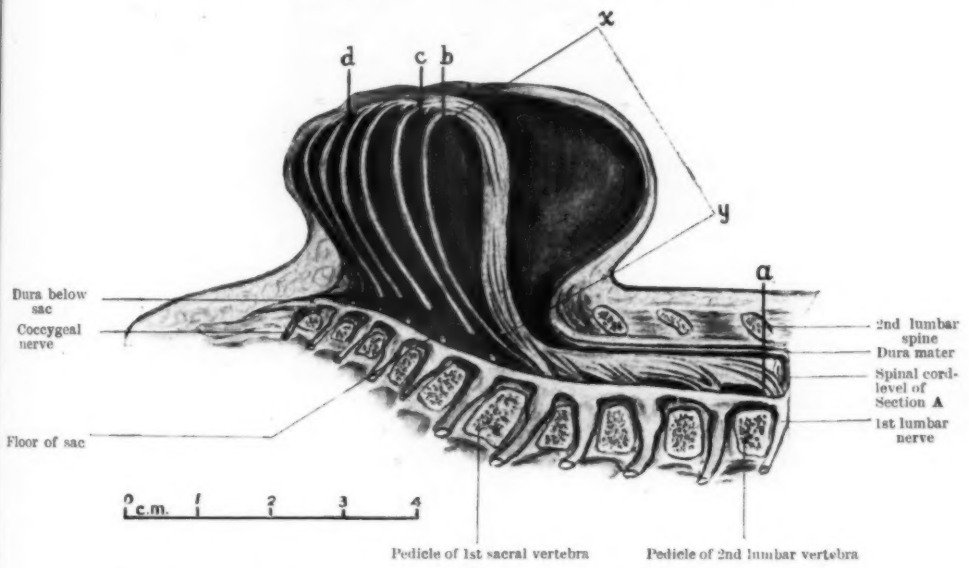


FIG. 10.—Case III, lumbo-sacral cystic myelocele. Longitudinal section through vertebral spines; exposure of pedicles of vertebræ on right side; right nerve roots above lesion shown; right nerve roots below lesion cut short; left sac wall and left roots within sac shown coursing across cavity. Drawing made from a composite of operative and post-mortem observations. Levels of microscopical sections indicated by letters a, b, c, d.

cyst into the foramina. This terminal portion of cord was cut across and the central canal found to be rather large, horseshoe-shaped and attached to but closed by the parchment skin of the sac. This was about the level of the first sacral vertebra. Above and below this point the parchment skin merged with a wall of well-formed dura, which was dissected free on each side and the edges sutured over the cord with chromic gut stitches. The remaining parchment was dissected till normal skin was reached and this was sutured. The baby left the table in a serious condition of shock and within the next hour developed feeble convulsive movements of the whole body, including the legs

and feet. Death occurred within three and a half hours after the completion of the operation. Only a partial autopsy could be obtained and had to be limited to the affected area, so that observations on the condition of the internal organs and upper part of the central nervous system are unfortunately lacking. The lower four lumbar vertebræ, sacrum and coccyx, were removed in their entirety with the surrounding tissues.

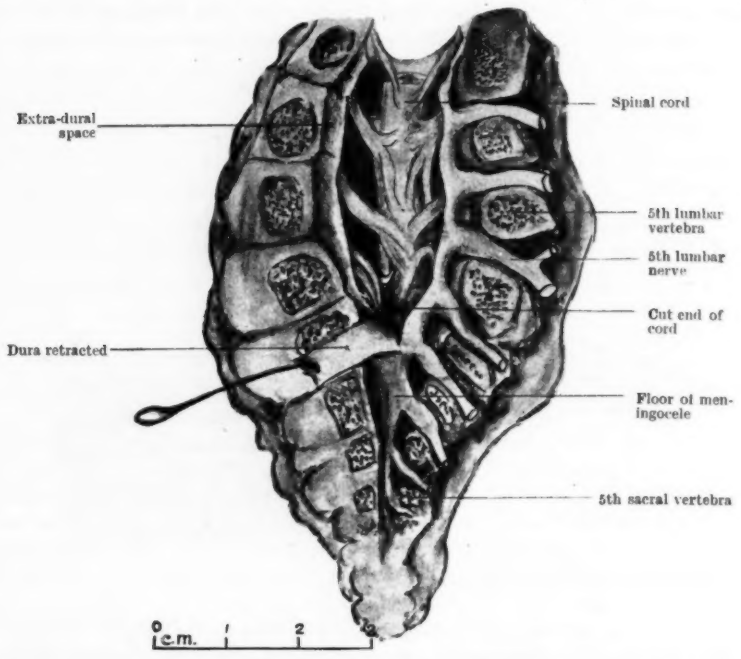


FIG. 11.--Case III, lumbo-sacral cystic myelocele. Dissection of specimen as removed post mortem. Bodies of vertebræ split in anterior median line, exposing cord from its anterior aspect. On the left side the vertebræ have been further dissected to show the pedicles.

Description of myelocele.—For the sake of clearness the description here given, like the accompanying diagram of the longitudinal section (fig. 10), will be a composite of operative and post-mortem observations. The sources of the information on each detail will be readily seen, but any attempt to separate the two sets of findings complicates the discussion unnecessarily. The laminæ and spine of the second lumbar vertebra are normally developed. The pedicles and transverse processes of the vertebral arches of the third and fourth lumbar are normal, but the laminæ and spinous processes flare outward, the vertebral foramen being closed dorsally by a dense fibrous band

extending between the bases of the arches. The fifth lumbar has no such band, but presents a widely open foramen. The laminæ and spines of all the sacral vertebræ are flaring and no fibrous band is developed.

Overlapping the third and fourth lumbar vertebræ, but not connected with them, is a thick meningeal sac which extends downward as far as the lower end of sacrum. This sac is covered by "parchment" of unusual thickness, which at the periphery is found to be composed of thin integument blending with a very dense dura, two or three times as thick as normal, which is in contact with a thin arachnoid. The subarachnoid space is filled with fluid. At the lower border of the fibrous neural arch of the fourth lumbar vertebra the meningeal layers of the sac are continuous with the sheath of the cord above, and the integument passes into the normal skin of the back. From beneath this fourth arch the cord emerges and passes dorsalward through the sac, surrounded by small nerve roots which are held in close contact with it by the pia. At a point a little below the middle of the sac the end of the cord becomes attached to the inner surface of its dorsal wall, and lower down is inseparably blended with it. Near the mid-line of the sac the dura fuses with the skin, and cannot be lifted from it though it retains its characteristic shining inner surface. The pia cannot be followed by the naked eye below the point of attachment of the cord, but at its lower end it is considerably thickened, and just below this it fuses with the other meningeal layers. From this point down to the lower limit of the posterior wall (roof) of sac, these fused meningeal layers form a definite band of dense white fibrous tissue which projects into its cavity. This band is augmented by the nerve-roots which are carried down along the cord, and also, as will appear later, by some poorly developed cord tissue. It is possible that in the tense condition of the unruptured sac this thickened band would have been apparent from the external aspect, and might have served as a clue to cord attachment. Below and laterally to the point of attachment of the cord numerous nerve-roots are seen passing from the inner surface of the roof of the sac traversing the cavity toward the intervertebral foramina. The upper and larger of these nerve-roots pass freely across the cavity, but the lower smaller roots run caudalward along the roof and then pass upwards a short distance on the floor of the sac in the substance of the arachnoid layer, which here is closely approximated to the dura. More careful study reveals the fact that those nerve-roots which arise from the saccular portion of the cord above its attachment to the sac wall, pass upward along the cord and enter foramina at a higher level than their point of origin.

In order to verify these observations, the anterior wall (floor) of the sac and that part of the cord above the lesion which had been removed after death, were exposed from in front by removing the bodies of the vertebræ. As is shown in the drawing of this dissection (fig. 11), not only the roots that arise from the intracystic part of the sac, but those which arise from the cord above the lesion, are found to course upward in the spinal canal before passing into their foramina. By a careful study of the relationships of the undivided

nerves above the operative section (B, in fig. 10) and of the divided nerves in the lower part of the sac, it is possible to determine that all the sacral roots and the coccygeal nerve were attached to the sac wall and were divided with it, and that the lower radicles of the fifth lumbar, as shown in fig. 10, were similarly adherent to the sac wall, but the upper radicles of this pair of nerves arose from the cord at some distance from its attachment to the sac, and passed up it to the foramina without interference from sac wall. Passing upward and examining the part of cord in the normal canal above the sac, one finds that the upward inclination of the roots decreases, but is still evident at the upper limit of the specimen, the roots from the level of the third lumbar vertebra passing through the twelfth thoracic foramen.

In fig. 11 it will be noticed that the nerve-roots exposed to view are somewhat curved owing to the relief of tension when the cord from which they arise was cut free from the sac wall at operation. This also accounts in part for the apparently small number and great thickness of the individual radicles as compared with the numerous delicate fibres found in normal cords. So soon as they have reached the floor of the sac the relationships of dura and of spinal ganglia and nerve trunks are entirely normal, and the anterior and posterior primary divisions of the sacral nerves pass through well formed foramina in the usual manner, though the position of the posterior foramina is obscured by the flaring vertebral laminæ. It is evident, therefore, that the cord must have lain in contiguity with the vertebral rudiments when these structures, the roots and ganglia, were developing, as the normal connections could not have been established across a large cavity filled with fluid. The fluid collection in the subarachnoid space must, therefore, have occurred after these connections were made, and may be a result of the impairment of arachnoid function caused by the adhesions at the mid-line already mentioned.

The upward direction of the nerve roots to their foramina of exit is due to two factors. To one of these reference has already been made in discussing Case I, and attention is again called to fig. 5, in which the normal cord migration and its modification in Case I is represented. In the specimen now under consideration the first sacral segment of the cord was held in contact with the skin so that it could not slip upward in the spinal canal as this elongated. Consequently the cord between this point and the fixed first cervical segment was stretched to the full length of the enlarging canal. Were this the only force at work the stretching would have been uniform throughout the length of the cord and the nerve roots would have continued to pass out horizontally to their respective body segments. However, the distension of the meningeal sac with fluid still further stretched the lower segments, so that they became actually longer than the spinal canal by the distance "x-y" indicated in fig. 10, and the nerve-roots above the point of cord attachment were carried below their foramina of exit to this extent, and so appear to ascend in the canal before emerging. This is shown diagrammatically in fig. 5, D.

The position of the roots below the adhesion of cord to sac is determined

by the same two factors, the fixation of the second sacral segment and tension by the sac, acting under different conditions. It must be remembered that in the normal migration of the cord, elongation of the roots takes place *pari passu* with the elongation of the canal, and the cord itself is never submitted to strain. In the meningocele, however, the tissues of the cord itself are stretched, and it seems possible that this may increase the minute histological defects found in these cases and so increase the amount of functional loss.

Microscopical examination.—Sections were made at the levels indicated in fig. 10. The region from the point of attachment of the cord to the end of the visible nervous tissue (*b* to *c* in the diagram), a distance of about four millimetres, was examined in serial sections, and those which are of the greatest interest are described. The transitional stages as illustrated in the intervening sections in the series are referred to between the descriptions of the separate sections photographed.

Section A.—Cord above the lesion (fig. 12, A) : This was removed from the level of the second lumbar vertebra, but the relations of its nerve roots show that it represents the twelfth thoracic segment. The arrangement of the motor cells is not that of the lumbar enlargement. The shape of the cord in section is roughly pyriform, with the wide part anterior, and a depression on each side posterior to the anterior horn. The anterior median fissure is shallow, the anterior commissure normal. The central canal is narrow just above the septum, and posterior to this has two wing-like projections irregularly lined by ependyma. It then passes posteriorly and can be followed by means of its ependymal lining to within a short distance of the posterior surface. In the section photographed no posterior median septum is present, but in sections from the same block of tissue slightly proximal to this the central canal blends with a definite posterior glial septum. Anterior horn cells are few in number, but well developed ; posterior horn cells cannot be identified with certainty, but a few nerve cells corresponding in shape and size with them are present in the region indicated in the photograph. The neuroglia in the whole section is loose in arrangement and œdematous, and contains an excess of small blood-vessels. Posterior nerve roots enter near the posterior mid-line ; their ascending fibres form a small posterior column which is normally placed. Other myelinated fibres from these roots pass round the distorted central canal to end in relation to the cells of the posterior and the anterior horns. On the left side other myelinated fibres which have ascended for a short distance in the posterior column are seen passing round in the same manner to the cells of the grey horns.

Anteriorly there is a quite normal distribution of myelinated fibres representing tracts which cannot be definitely differentiated from one another in a normal cord of this age. The antero-lateral fasciculi are very prominent. An area of less definite myelination probably represents the lateral cerebrospinal bundle. On the left side of the section there is a group of cells (*subgel.*), which probably correspond to the gelatinous substance. On the right side there is no similar group in this region but there is a less definite group in

relation to the entering fibres of the posterior root. It will be recalled that the gelatinous substance normally lies as a cap on the posterior horn, between it and the entering fibres. One or two myelinated fibres cross in the anterior commissure. There is an appearance of crossing fibres in the posterior commissure, but a careful reconstruction from the study of many sections from this area shows that these are fibres from the homolateral posterior column passing round the dilated central canal. The collapse of the central canal has caused a tear in the posterior part of the cord to the left of the median line, and the relations of structures in this region are much altered by the distortion. This has rendered the interpretation of the findings exceedingly difficult, but could not be avoided as it was the result of the operative procedure. In the uncollapsed specimen the central cavity must have been nearly circular, with its posterior wall composed of glia and nerve fibres and its anterior wall of the grey horns and anterior part of the white matter.

Section B (fig. 12, B).—This section is taken at the lower end of the cord, just before its attachment to the sac wall. The distribution of the nerve radicles from this shows that it represents the first sacral segment. Owing to the obliquity of the attachment to the sac wall the section shows a great enlargement of the cord in an antero-posterior direction. The transverse diameter is about normal. There is a well-marked anterior median fissure but no definite posterior median septum. The central canal is enormously enlarged and irregular in shape; its walls are collapsed as a result of the operation. The ependymal layer is present in the anterior portion of the cavity, but is lost posteriorly. This is the case in all the sections of this region, and appears not to be an artefact but to indicate a communication of central canal with an adventitious cavity.

In the substance of the medullary tissue are a few small collections of fluid, and the nervous elements present a loose arrrangement, presenting evidence of œdema. There is in many places an apparent absence of nerve cells or fibres lying between the meshes of glial fibrils, and there are but few neuroglia or neuroblastic cells. Round the central canal there is a tendency for the cells to be spindle-shaped and to retain somewhat the type of the spongioblast of the mantle layer of the embryonic cord. In the posterior region there is no trace of posterior horn cells, but posterior nerve-roots are myelinated and enter normally. In the anterior horn there is a well formed group of cornual cells of normal size, corresponding roughly in arrangement to those of lumbar enlargement, and the emerging motor fibres are myelinated and numerous, but somewhat irregularly grouped. The antero-lateral fasciculi proprii are myelinated and normally placed; no other tracts are distinguishable. The membrane covering this part of the cord is thicker than normal; and though laterally and anteriorly it appears to be composed of inflammatory pia only, posteriorly it blends with a dense layer which represents fused arachnoid and dura. Posteriorly also there is much leucocytic infiltration, probably due to the proximity of the inflamed sac wall.

Immediately below this section the cord was so fimly adherent to the sac

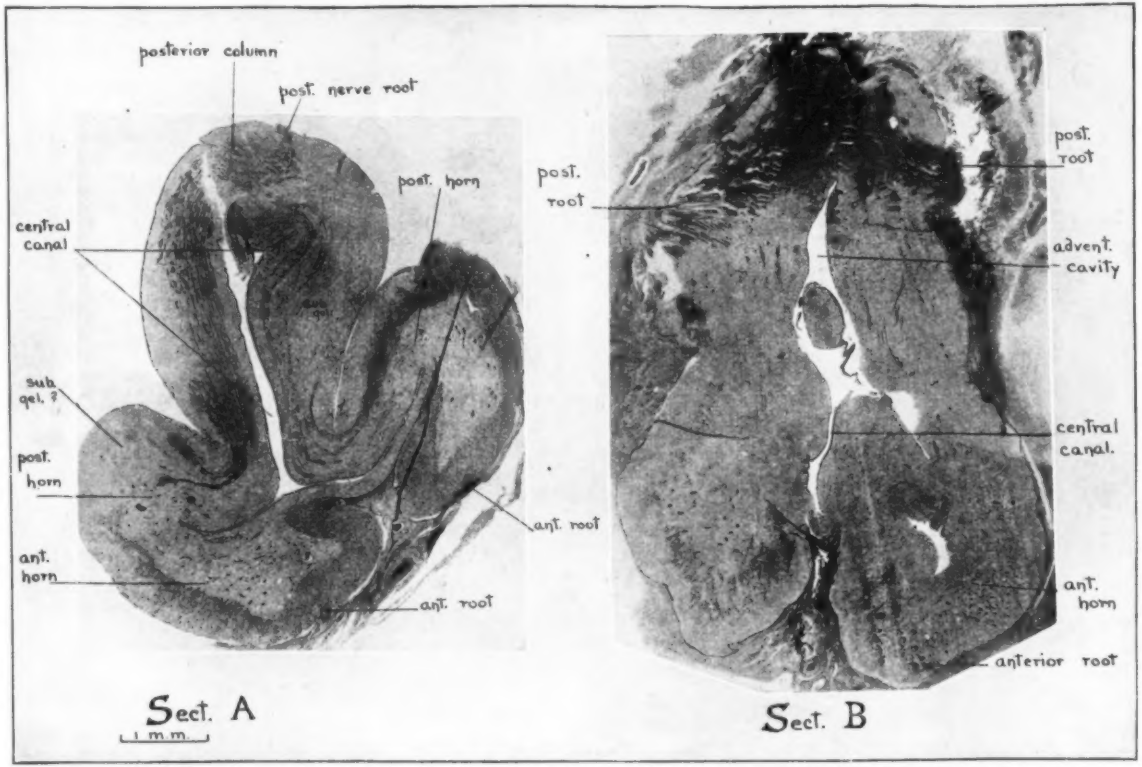


FIG. 12.—Case III, lumbo-sacral cystic myelocele. Photomicrographs of Sections A and B at the levels indicated in fig. 10.

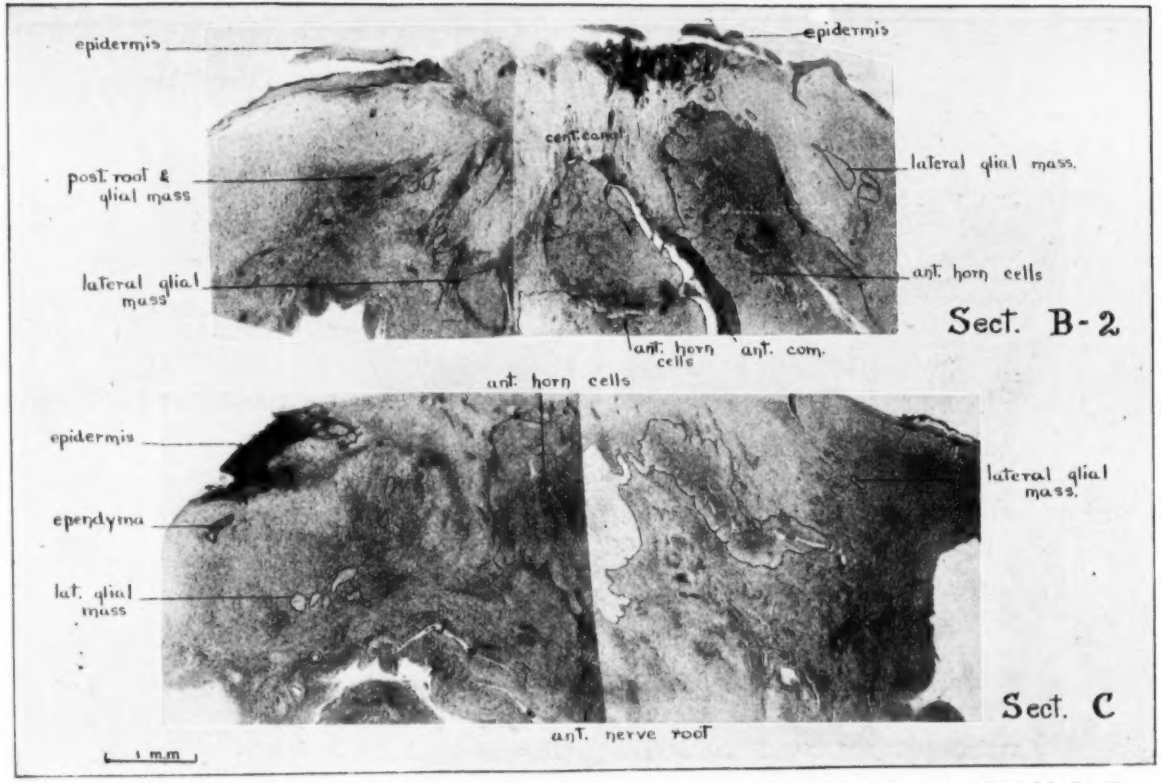


FIG. 13.—Case III, lumbo-sacral cystic myelocele. Photomicrographs of Sections B-2 and C, at the levels indicated in fig. 10.

wall that sections were made through this in order to preserve the posterior portion of the cord tissue. The first of the serial sections examined from this region (between B and C on fig. 10) shows that the posterior part of the cord is spread laterally as it becomes attached to the wall of the sac, and the adventitious cavity in Section B enlarges and approaches the surface. In the posterior attached portion less and less nervous differentiation remains, so that in the distal sections it appears only as a glial mass lying in the subcuticular connective tissue layer. This glial mass is separated into two parts by the extension of a fibrous band through the posterior median line towards the anterior median septum. In more distal sections this band of adhesions spreads into the posterior cord tissue laterally, and finally breaks it up into small, partly differentiated, neuro-epithelial masses. At the same time, the central canal persists in the anterior part of the cord but narrows as it approaches the posterior surface. The anterior median septum extends dorsally until it finally reaches and becomes fused with the subcuticular layer of fibrous tissue, thus separating the anterior portion of the cord into two lateral halves. In each of these a prolongation of the central canal persists for a time. In one of them it is carried somewhat more caudally than in the other. On account of the obliquity of the cord in this situation the interpretation of the sections is by no means easy.

Section B-2 (fig. 13).—The position of this section is half-way between B and E as indicated on fig. 10. There remains but little of the posterior part of the cord, and only in scattered masses close to the surface epithelium. At the median line the surface epithelium is thinned and in some sections absent, and beneath it there are many inflammatory cells in the fibrous tissue which separates it from the cord substance. The anterior part of the cord, recognized by a few motor cells, is separated into two halves by the adherence of the anterior median septum to the surface fibrous layer. The depth of this fibrous bridge and of the nervous tissue is increased by the obliquity of the section. At the point indicated in the photograph there remains a trace of the anterior commissure which persists for a few sections below this point and then disappears. No myelinated fibres are present except a few in the anterior part of the cord coming from anterior horn cells. The anterior roots and the extreme anterior part of the cord have been cut off by the removal of Section B. The posterior roots are non-myelinated and consist of but few nerve fibres with an excess of fibrous tissue; they lie close to the surface epithelium and are lost in the fibrous subcuticular layer before they reach the cord. At the left in the photograph (*cent. canal*) there remains a small ependymal-lined cavity, the prolongation of the central cavity of higher sections. This is carried farther down on the left than on the right side. Both the nervous masses are connected with the thinned epidermis by strands of undifferentiated epithelium, infiltrated with inflammatory cells. The nervous masses are considerably broken up by adventitious connective tissue trabeculæ and by inflammatory material. The condition here recalls Case I, fig. 9, where the ribbon cord passes into the closed distal segments. In

Case I, the transition is not obscured by adhesion to skin, and the bifid character of the central canal is more easily seen. In these the open segments are adherent to skin, and the relations are so altered that the stages are difficult to recognize.

Section C (fig. 13, C).—In this section the anterior part of the cord is still recognizable; one or two anterior horn cells are present in each lateral mass. On the left side an anterior nerve root emerges, but it contains no myelinated fibres, nor are there any in the anterior cord rudiments. Posteriorly irregular epithelial strands connect the nervous masses with the surface epithelium. (The loss of epithelium over the middle portion of the photograph is an artefact.) Laterally there are many small collections of partly differentiated neural epithelium, which appear to represent the posterior portion of the cord. On the left side one of these contains a cavity with a well developed ependymal lining, which has no connection with any other; it persists for but a few sections proximal and distal to this level.

In the remainder of the serial sections from this region the posterior (lateral) collections of neuro-epithelium become more and more attenuated and invaded by the surrounding fibrous tissue; the anterior masses remain recognizable for some distance, and are still present in the next section to be described.

Section D (not photographed).—At a distance of 10 mm. from Section C. The anterior masses are distinguished only by their position and relation to those in higher sections. No motor cells are present, yet nerve-roots approach close to the deep surface of the nervous tissue, and at certain points there appear to be emerging bundles of non-myelinated fibres. Between the integument and the neural masses there still persists an irregular and broken epithelial connection.

For a short distance below the last section nervous tissue is demonstrable, and nerve bundles are present in the connective tissue to the caudal limit of the sac wall.

Case IV.

Cystic myelocele—rachischisis completa restricta of Class 3 (A).

History.—M. E. H., female, aged three weeks.

Father and mother healthy, except that mother has a "weak back," but had no trouble while carrying child. Baby has one brother, aged 6, who had "infantile paralysis" at age of 1½ years, which has left his legs weak, though all the muscles seem to be equally developed. His sphincter control is normal. No examination of his back was made. No history of congenital defect in other members of either side of the family.

Description of condition.—Baby well formed, except for spina bifida. Nutrition good; no hydrocephalus apparent. In lower lumbar region is a tumour size of half a mandarin orange, covered by parchment skin, ulcerated on the surface and covered by a transparent dressing. On removing this the ulcerated area bleeds, but shows no purulent discharge, nor spinal fluid.

Pressure near or on sac causes the baby to cry. Urination and defæcation occur frequently, especially when the child cries or the sac is touched. Movements of thigh are normal. In a position of rest the legs are kept straight, but passive plantar flexion causes slight active flexion of the knees. The feet lie in a position of flaccid semi-extension, and the usual "curl" of a baby's foot is absent. If the foot is irritated the extensors act so as to pull it into a position of dorsiflexion on the ankle, but the toes seem not to move. No response of any kind could be obtained to tickling sole of foot or pressing calf muscles. No attempt was made to determine the state of sensation in the thigh or perineum. Pre-operative diagnosis: meningocele; position of cord not determined unless indicated by ulceration of surface. Muscular responses probably indicate that the tibialis anterior (L. 4 and 5 and S. 1) and extensor longus digitorum (L. 4 and 5 and S. 1) are approximately normal. Peronei (L. 5 and S. 1) and small muscles of the foot (L. 5 and S. 1 and 2 and 3) are involved to some extent. Gastrocnemius and soleus (L. 5, S. 1 and 2); and the urethral and anal sphincters (S. 1 and 2, 3 and 4, Dejerine) are apparently completely paralysed. It seems probable that all the sacral nerves are affected; that the fifth lumbar is slightly so, and that the fourth lumbar is normal.

Operation by Dr. J. E. Thompson, October 30, 1920, under ether anæsthesia. Baby had irregular respiration from the time sac was opened until close of operation, but colour remained fair. Transverse incision. Parchment skin removed, cord found to be rather large at its termination, and to be attached to the sac at the middle where ulceration had taken place. The cord was cut free as close to sac as possible, and its end ligated. It was ovoid in shape and presented a rather large cavity. The level of its attachment was about opposite the fourth lumbar vertebra. Across the sac several large nerves coursed, and two of these on each side passed along cord to the roof of sac to which they were attached by delicate fibrous bands. These were separated, but it was thought that in cutting the cord at its attachment the roots of these were severed. One or two very fine nerve filaments were cut from the lower part of the sac roof below attachment of cord, which probably belonged to the lower sacral or coccygeal. It was impossible to separate these, and their roots had been necessarily cut with the end of cord. Dura and skin were separated at the side of sac and the wound closed in two layers, with a small gutter drain at one end under skin. Post-operative course, October 30, 1920: Condition remained good during day of operation, though the baby had one or two attacks in which the face became cyanotic, but the rest of body remained of good colour. Respiration appeared good during the attacks, which lasted fifteen or twenty seconds. These attacks continued to come more frequently and to be more severe, with irregular respiration. On November 1 the tube was removed from the wound, and was followed by considerable leakage of spinal fluid. This continued to drain profusely for some days, then became gradually less, but was still slight when baby was discharged. During the remainder of this day (November 1) baby took no nourishment; had twitch-

ings of the face and jerking of the eyes to the left (it was lying on the right side). These attacks of facial twitching became increasingly severe. They were at first accompanied by cyanosis, but this became less though the nervous phenomena increased. Attacks occurred whenever the child was disturbed or there was much noise. After an attack the baby seemed worn out, and would drop into a troubled sleep. On November 3 she seemed to regain strength, cried normally, and took some nourishment; but still had some attacks of facial twitching and slight cyanosis. Spinal fluid was draining freely from wound. November 4: had a severe attack of dyspnœa with twitching of the face, mouth, and eyes, and mild general convulsions. Attacks of this nature occurred frequently from 7 p.m. to 10 p.m., and then became less frequent and severe. November 5 and 6: had similar attacks, but of decreasing frequency and severity. On November 7 she had no severe attacks and was nursing better. Drainage from wound was slightly turbid and yellow for the first time. Similar discharge occurred for the next three days, after which there was only a slight drainage of clear cerebrospinal fluid. On November 11 "nervous attacks" ceased entirely, and from then on the baby's condition steadily improved. She left the hospital a few days later. Immediate operative result: No change could be seen in the muscular power so far as it could be determined after the operation. The nurse and the mother said that the big toe and the second toe were extended from time to time, but this was never observed by Dr. Thompson or the writer.

Description of the myelomeningocele.—In this case it is only possible to give the operative findings and the description of the sac as removed, so that all information regarding the cord above the lesion and accurate data regarding the relations of nerve roots and floor of sac are lacking. As viewed at operation, this case vividly recalled the appearance of Case III, and if the reader will refer to the diagram (fig. 10) of that case, the description of the conditions found in this case will be much more intelligible. The conditions found at the operation were: the end of the cord was rather large and distended with fluid, and attached to the sac at its mid-point, which in the distended condition of sac was thought to lie about opposite the fourth lumbar vertebra. Across the sac several large nerve roots passed, and two of these on each side ran along the cord, apparently attached with it to the roof of the sac. Below the attachment of cord one or two fine filaments were seen passing down from the roof of the sac to its floor; they were thought to represent the lowest sacral and possibly the coccygeal nerves.

Roof of sac: Immediately after the operation the removed area of sac was pinned out on cardboard, so as to preserve as nearly as possible its size and shape. It is very nearly circular, measuring 6½ cm. by 6½ cm. in the long and transverse diameters, and when seen from the posterior aspect (i.e., the external surface) all of this except a central area of about 5 mm. was found to be parchment skin, the peripheral area being covered by thin, fairly normal integument. The anterior aspect (fig. 14) is found to be clothed with a shining dura, which is inseparable from the surface layer, and within this is a delicate

arachnoid layer. Two and one-half centimetres below the upper limit of sac the cut end of the spinal cord is found, and from this point downwards, as is shown in the diagram, there extends a band of tissue 16 mm. in thickness at its broadest part, and narrowing slightly as it reaches the end of the sac. This band is irregular in shape, and somewhat hemorrhagic where it is continuous with the end of the cord, but below this region it is flat, shining, and rather sharply marked off from the remainder of the sac by two longitudinal bands of fibrous tissue. A vein which runs down the middle line of the band conforms in appearance with the anterior median vein of the cord. On the edge of the band the arachnoid appears to blend with the pial layer which covers it. Apparently the two lateral fibrous bands represent the ligamenta denticulata, but none of the lateral denticulations could be seen. In the upper portion

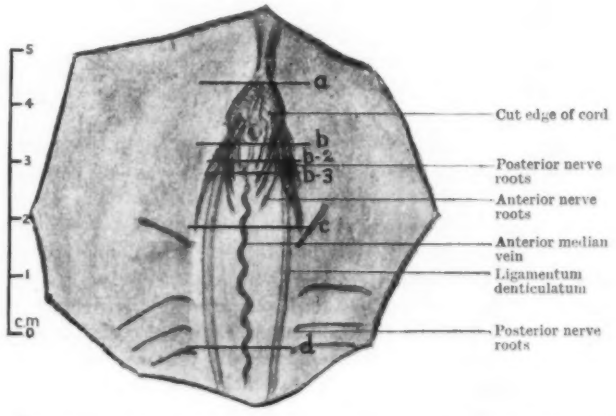


FIG. 14.—Case IV, lumbo-sacral cystic myelocele. Interior of sac as removed at operation, showing band of altered cord tissue, and the region of cord attachment. Levels of microscopical sections indicated by letters a, b, c, d.

of the median band, medial to the ligamenta denticulata, it is possible to find a few delicate nerve filaments representing anterior roots proceeding outward and upward on the sac roof, and apparently cut off with the end of the cord. These cannot be found in the caudal 25 mm. of the band. Lateral to the ligaments, nerve filaments (posterior roots) can be found lower down, to within 10 mm. of the end of sac. These filaments are very delicate and lie free in the sac; they do not arise from the cord above, but directly from the band of tissue just described. If the inference drawn at operation be correct, that these two roots are the fifth sacral and coccygeal nerves, by counting back from these it should be possible to determine with more or less accuracy the segment of cord attached to the sac. This is probably the first sacral or fifth lumbar, and the clinical examination appears to corroborate this. The presence

of these nerve roots would lead one to expect to find nervous tissue in the median band as low down as the last pair of roots, but by the naked eye nothing resembling normal cord tissue can be seen below the point where the cord has been cut obliquely free from the sac wall. A section immediately below this point, through the sac roof, shows a soft cystic friable mass of tissue, and sections below this reveal only a pink, soft mass of tissue, slightly thicker than the rest of the sac wall, extending laterally a little farther than the band of tissue described on the inner surface, but having no resemblance to cord tissue. As will be seen, however, the microscopic examination of sections through this region are not disappointing.

Microscopical examination..—The sections described were made at the levels indicated in fig. 14, through the median band. The end of the cord had been severed by the operative procedure so close to the sac wall that no section of it could be made before its attachment to sac. At its point of attachment serial sections of the entire region were made, and the photographs are selected from these. The area so examined extended from A to C in the diagram ; the changes observed in intervening sections of the series are noted between the descriptions of the individual sections.

Section A (fig. 15).—This was taken proximal to the point of cord attachment, but the lower sections of the block show a small part of the cut surface of the cord. The surface is covered by thin, stratified, cornified epithelium, below which is a dense layer of connective tissue, representing fused corium and dura. Below this laterally is a thin layer of connective tissue covered by endothelium, the arachnoid, which, thickening as it nears the mid-line, becomes blended with the pia and lies in direct relation to the posterior part of cord tissue. The upper limit of the adherent portion of cord is here seen represented by a mass of glia, in which no nerve cells nor myelinated fibres are present. The anterior part had been cut away in the operation.

Section B (fig. 15, B).—This section is taken immediately distal to the point of cord attachment, and is the first of the series through the region which has not been affected by the operative incision. It is probable that it represents the first sacral segment of the cord (cf. gross description). As will be seen in the photograph, the surface here is covered by a thin layer of stratified squamous epithelium, imperfectly cornified, and having none of the normal skin glands nor papillæ. Immediately below it is a mass of connective tissue which is in parts densely infiltrated with leucocytes and with blood.

Below this layer of connective tissue there is a dilated cystic cord, of which the anterior portion only bears any resemblance to normal cord structure. Laterally the subcutaneous connective tissue is found to blend with an imperfect dural and arachnoid layer, but in the region where nervous tissue exists these are not present. The cord anteriorly is clothed by a thick layer of vascular connective tissue, apparently a thickened outer layer of pia mater in which lie nerve roots ; and within this is a delicate connective tissue membrane, which appears to represent the inner layer of the pia. Both these layers are lost posteriorly in the subcutaneous connective tissue layer already mentioned.

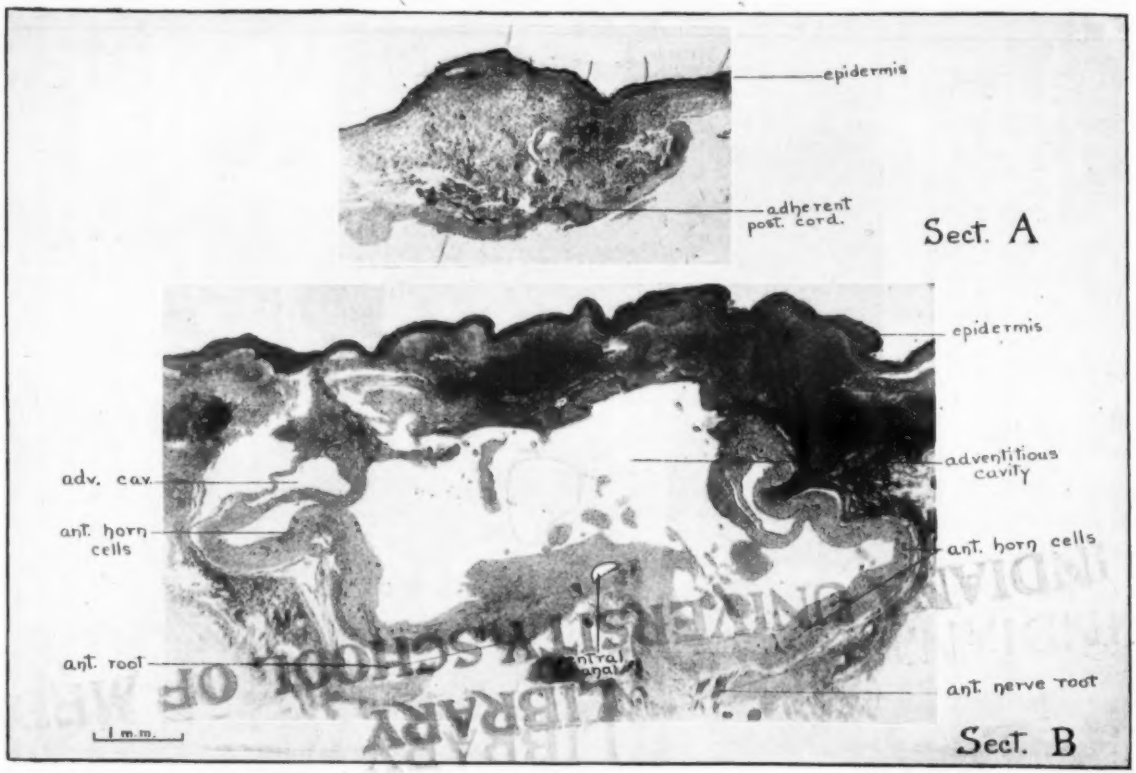


FIG. 15.—Case IV, lumbo-sacral cystic myelocele. Photomicrographs of Sections A and B at the levels indicated in fig. 14.

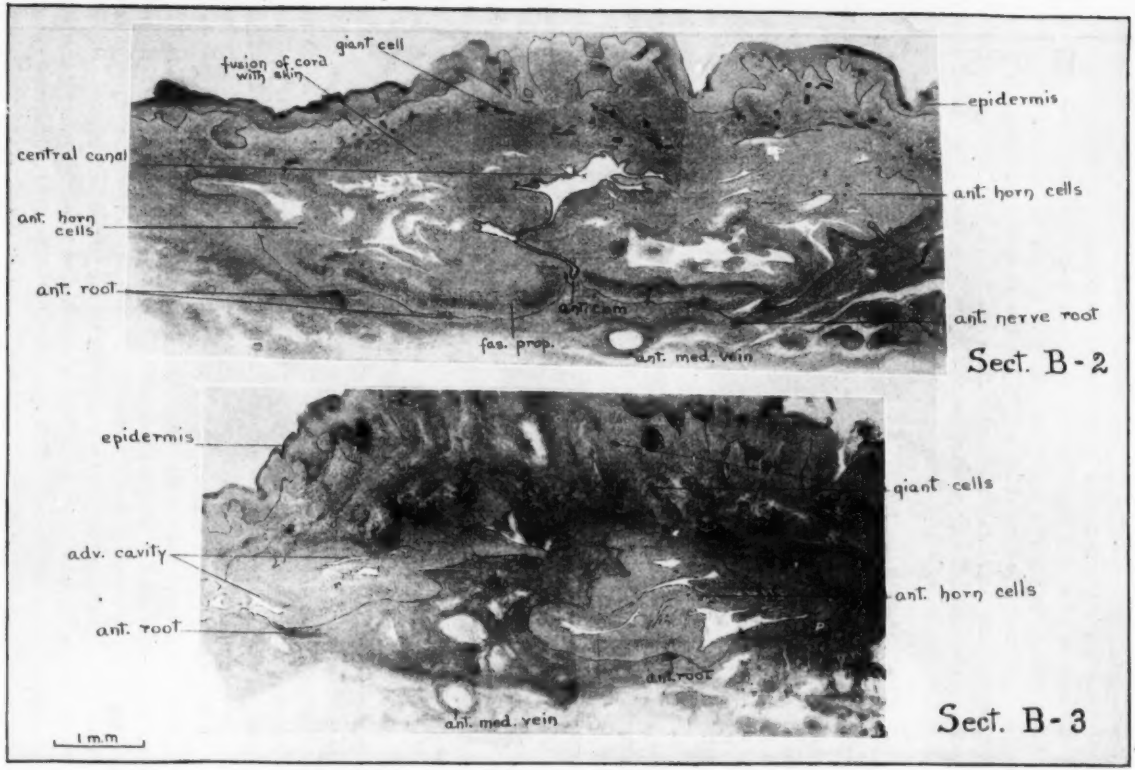
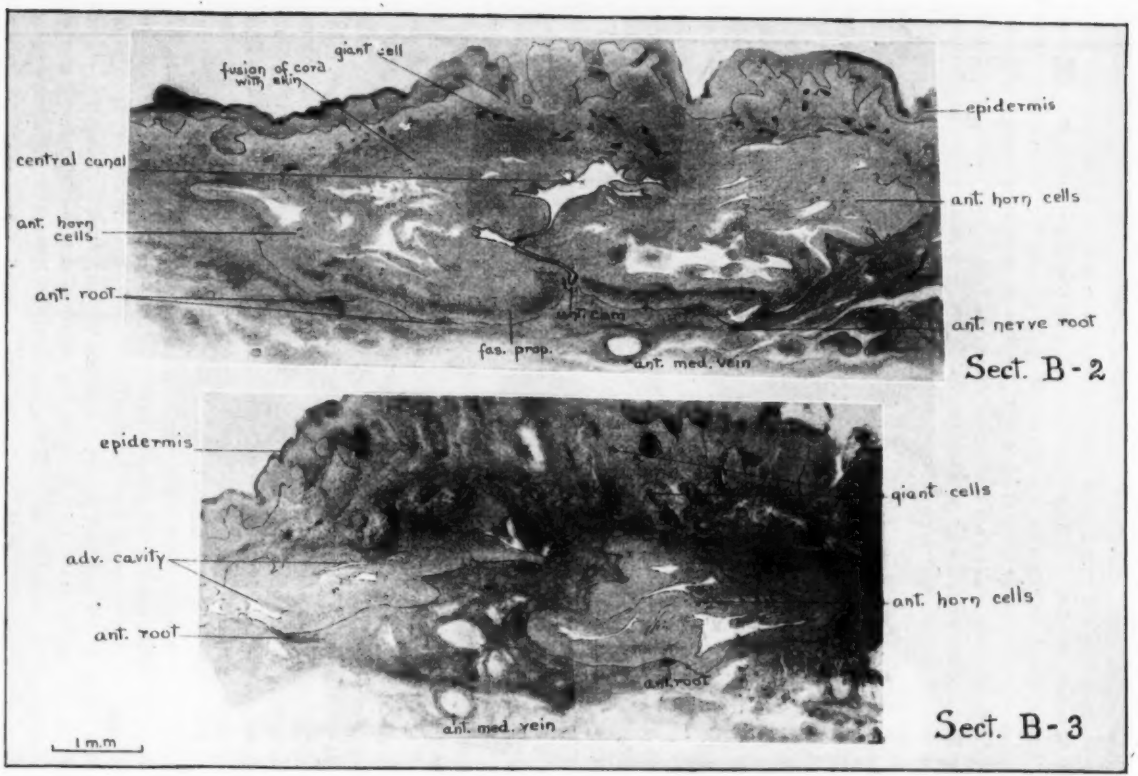


FIG. 16.—Case IV, lumbo sacral cystic myelocele. Photomicrographs of Sections B-2 and B-3 at the levels indicated in fig. 14.

The most striking feature in the cord is a large, irregularly-shaped fluid-filled cavity, which in the section is much distorted by the operative procedure. This is not a dilated central canal; it is not lined by any membrane, but by the neuroglia of cord substance. Posteriorly on each side is a smaller cavity, separate from the main cyst, which in the light of observations on other cases may possibly represent the position of undeveloped posterior columns. No trace of the posterior horns or columns can be found, but there is an irregular mass of neuroglia on each side. Toward the mid-line these masses are lacking, and the cavity in the cord tissue is bounded by the subcutaneous connective tissue layer. Anteriorly there is a well-formed, ependyma-lined central canal, and on either side of this well-formed anterior horn cells can be found, irregularly grouped along the anterior wall of the cystic cavity. Myelinated fibres are seen to pass from these and to emerge as fairly large anterior nerve roots. There are also numerous myelinated fibres forming a marginal zone over all the anterior half of the cord; these are probably all association fibres.

In the connective tissue surrounding the cord the nerve bundles are found arranged in two groups; one of these lies anterior to the cord in the mid-line, and then passes outwards to the sac wall. Into this group the anterior root fibres may be seen to pass from the cord. The other group lies close to the surface epithelium, and none of the fasciculi can be traced to the cord. It appears that the fibres in this second group represent the posterior roots approaching the cord from the spinal ganglia, but they never reach it, otherwise some should have been found in the great number of sections examined. This presupposes the proper development of the spinal ganglia, which is not owing to the circumstances of the case capable of proof. As has been seen, however, in the discussion of Cases I and II, the spinal ganglia sometimes develop even in cases with more marked neural tube defects than are here present, and the relationships of these fibres placed posteriorly to ligamentum denticulatum, makes it reasonably certain that they represent posterior roots. Between Sections B and C the cyst rapidly narrows. Microscopically the small central canal which is present in Section B enlarges posteriorly, and gradually assumes the proportions seen in the next section. It does not, however, communicate with the adventitious posterior cavity, but extends dorsally until it comes in contact with the subcuticular fibrous layer, and thus separates the adventitious cavity into two.

Section B-2.—Three millimetres below Section B (fig. 16—B-2). The most striking feature of this section is the huge central cavity which abuts directly against the subcuticular fibrous layer without the intervention of any nervous tissue. Its ependyma is unbroken, and the irregularity of shape is due to collapse of the wall in preparation. On either side the adventitious cavity seen in Section B is similarly collapsed and is broken up into smaller compartments. The anterior median fissure is shallow, and the anterior commissure hardly discernible. Anterior horn cells are still present but are few in number. There are a few myelinated fibres in relation to the anterior horn cells and in the region of the antero-lateral fasciculus proprius, but the anterior



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roots, which are found in the region indicated in the photograph, are largely non-myelinated. All the rest of the nervous tissue is composed of undifferentiated glia and possibly unmyelinated fibres.

In the following sections of the series the central canal becomes smaller, first anteriorly, and in lower sections posteriorly also, and the anterior median fibrous septum passes more and more dorsally until at the point where the central canal disappears entirely the nervous tissue is separated into two halves by the fusion of the anterior median septum with the fibrous subcuticular layer.

Section B-3.—Two millimetres below Section B (fig. 16—B-3). In this section one or two anterior horn cells may still be found. The nervous tissue is separated into two masses by a thick septum of fibrous tissue which extends dorsally to the subcutaneous tissue; in each of these irregular adventitious cavities are present, the continuation of those seen in higher sections. One or two anterior horn cells are present; but the remainder of the nervous masses, composed of glia and possibly unmyelinated fibres, can hardly be recognized as cord tissue. Between the surface epithelium, which is partly destroyed in the median line by ulceration, and the nervous tissue, a small number of giant cells are present and a few irregular epithelial strands.

Distal to this section the nervous masses become more and more indistinct, and about one millimetre below this level the appearance is exactly similar to that in Section C, though this is taken at a lower plane.

Section C (not photographed).—Through the median band, 11 mm. below Section B (fig. 14), 6 mm. below Section B-3. Laterally the character of the surface epithelium, connective tissue and meningeal layers is precisely like that in Section A. In the middle 10 mm. of the section, however, the surface epithelial layer loses its stratification, and merges into a mass of ulcerated imperfectly differentiated epithelium of considerable thickness, which is ulcerated and forms the bulk of the section in this region. Many small blood-vessels course through this mass, and its deeper layers are crossed by transverse bundles of fibrous tissue. Deeper down it is rather sharply limited by a connective tissue layer corresponding in appearance with the pial layer in the preceding sections. Between this and the more superficial connective tissue are irregular masses of epithelium of embryonal appearance, some of which are clearly neuro-epithelium.

Scattered through the epithelial masses are many irregularly shaped giant cells, such as are found in the two preceding sections. Some are of great size, and contain large numbers of irregularly disposed nuclei. They do not conform to the type of the usual foreign body giant cell, and are difficult to explain. None are found beneath the pia. Probably they are endothelial in origin and may represent imperfect budding capillaries. The elongation of some of the larger cells, and the presence of red blood cells in one or two, seem to bear this out.

Section D (not photographed).—This section is taken 14 mm. below Section C, at a point where the thickened median band begins to thin out near the

end of the sac. It shows the surface and meningeal layers already described in Section A, and is of interest only because of the absence of the giant cells seen in the last section, and because laterally it possesses medullated nerve fibres, though it contains no cord elements. These are the posterior roots described and shown in fig. 14. The examination of sections between this and Section C shows that they do not pass up to the well-formed cord above, but are lost in the fibrous tissue.

Case V.

Hydromyelo-cystocele—rachischisis completa restricta of Class 3, A.

Specimen No. 77, University of Texas Pathological Museum (1893).

History.—The baby had been admitted to hospital at the age of 1 year for treatment of a lumbo-sacral meningocele. Following the injection of Morton's fluid, then in use (1893), the baby promptly died. No facts regarding muscular power are available; the baby had double congenital talipes equino-varus.

Description of specimen (fig. 17).—All the lumbar and sacral vertebræ had been removed with the tumour, bisected along the mid-ventral line and spread apart so as to expose the cord and the floor of the tumour from in front. Posteriorly the greater part of the right wall of the meningeal sac has been dissected away so as to expose its interior.

The upper three lumbar vertebræ are normal; the spine of the fourth lumbar vertebra is slightly smaller than normal: the fifth lumbar is cleft, its laminæ and spines flaring outwards. The columns of the sacro-spinalis muscle spread outward also so as to obtain attachment to the flaring spines. All the sacral vertebræ are bifid; but while the spines of the upper three flare, those of the last two are not more widely separated than in the normal sacrum. Through the opening in the spinal canal, the meninges and cord pass dorsalward. The meninges are adherent to skin and form a large sac, to the middle of which the cord is attached. It measures 4 cm. in antero-posterior and $3\frac{1}{2}$ cm. in vertical diameter, but shows evidence of shrinkage during fixation. The skin covering it is fairly thick and has the appearance of normal integument, but section shows that it is without a fatty layer, and that its inner surface is inseparably fused with the dural layer of the sac. The further study of the sac will be simplified by reference to the drawing (fig. 17) which was made from the specimen and reproduces as nearly as possible the results of dissection. The only feature in which it is diagrammatic is that the cord is represented in longitudinal section throughout the whole of its upper portion, and the central canal as greatly enlarged. This was not visible to the naked eye in the dissection because of the collapse of the walls of the cord from the point B in the drawing, to the upper end of the cord in the normal canal; the dilatation is, however, easily demonstrable in sections at various levels. This will be more fully explained later.

Under the fourth lumbar arch the cord passes dorsalward at a sharp angle

to the roof of the sac, where it flattens out and adheres to the middle of its roof. Above its point of attachment a fairly strong connective tissue septum extends downward from the sac roof to the lateral surface of the cord, where it blends with the pia. Where the cord passes into the normal canal above, i.e., at the " neck " of the sac, this septum is very narrow and fuses on the ventral side with the pia around the cord and on the other with the dura mater of the sac wall. In the dissection only the left side of the cord

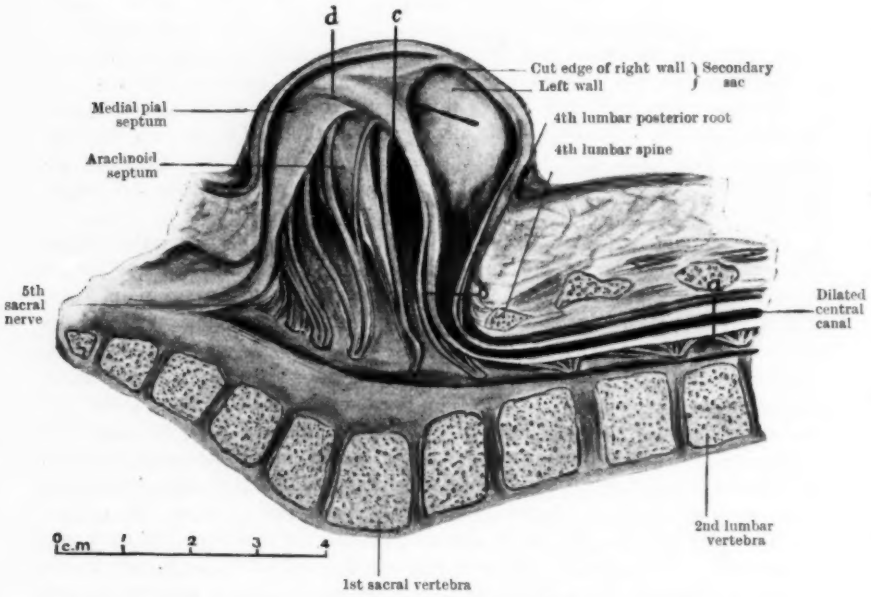

FIG. 17.—Case V, lumbo-sacral cystic hydromyelocele. Longitudinal section through sac as removed at autopsy. Cord had collapsed as result of a fixation from the point b upwards, and is represented in its dilated condition. In all other respects the drawing accurately reproduces the condition of the preserved specimen. A probe is passed into the right lateral pocket of the dilated cord cavity. Levels of microscopical sections indicated by letters a, b, c, d.

shows this septum, but along its right aspect there is evidence that a similar septum had been cut away, and that in the original condition the cord was slung between these two. On examining the posterior portion of the cord between the septa, it is found to be degenerated and to bear no posterior root fibres. Where the cord emerges from the canal and enters the sac nerve roots may be seen to pass from its posterior surface and to blend with the upper part of the roof of the sac as shown in the diagram. The anterior surface of the cord appears to be normal and its nerve roots pass out

and course forwards toward their foramina. It seemed probable from the dissection that the septa just described had enclosed within them the dilated posterior part of the cord, and further study proved this to be the case. The preservation of the sac wall had not been sufficiently good for any nervous elements to remain uninjured in the exposed region where the right septum had been dissected away. It is found, however, that where the end of the cord joins the sac wall it is much flattened and that the secondary sac just described passes into two lateral pockets. One of these, the right, is shown in the drawing with a probe passing into its depths. These pockets terminate close to the lateral masses of the cord tissue below, and, as will be seen later, they are lined by ependymal cells. Moreover, at the point B in the diagram, where the cord in the preserved specimen is small and flattened, section shows that its walls are thin and fluted, indicating that it had been greatly distended with fluid. Higher up in the normal canal the cord appears flattened in an antero-posterior direction, and here also gross and microscopic section shows that there has been collapse of a large interior cavity. This and other microscopical observations prove that the secondary sac consists of a cyst of the dorsal part of the cord, surrounded by pia and adherent to the sac surface, and it is so represented in the diagram.

Distal to the attachment of the cord, another delicate septum extends like a veil about half way through the depths of the sac, and laterally on the left side (the right side has been dissected away) is another septum which terminates higher in the sac wall. The relationships of the nerve-roots to these septa show that the medial veil is pial and the lateral is arachnoid.

As is shown in the drawing, the lower part of the sac is traversed by many nerve-roots. These lie medial to the arachnoid septum and lateral to the pial septum mentioned, and are more or less entangled in delicate fibrous trabeculæ, which bind them to the sac wall. The last roots which emerge from the well-formed cord, before its attachment to the sac roof, are the fifth lumbar roots, and of these the anterior radicles come from the cord, and the posterior roots from the sac wall where it is adherent to the posterior cystic cord. The roots below these are fairly large, but not so large as those in a normal fœtus at term. They are divided into two groups, anterior and posterior, which unite in the usual manner and pass into foramina in the floor of the sac. They do not, however, appear to join any normal cord tissue on the roof of the sac, but to come directly from the sac wall at a point below the demonstrable cord. It was not possible to dissect these after they became adherent to the roof of the sac, as they are fused with the dense tissue of its dural lining.

The arrangement of the roots above the lesion is, perhaps, sufficiently clear from a study of the diagram alone, since it is in no way different in principle from that found in Cases III and IV, of which full explanation was given.

Microscopical examination (figs. 18 and 19).—Sections were made at the levels indicated in fig. 17. In spite of the age of the specimen the staining with iron-hæmatoxylin was very satisfactory, though the other stains were not successful. The only serious difficulty was that the tissues were so friable

that it was difficult to cut blocks for examination without tearing the sections. This was especially true of the dilated cord as it entered the sac. In the removal of the right myelocele wall the pia had been incised, and when Section B was cut its walls spread into a long thin ribbon of tissue, and lost their circular conformation. The examination of the sections was, as a whole, much more instructive than one would expect after so long a time in preservatives.

Section A (fig. 18).—Level of the second lumbar vertebra, above the lesion. The foramina through which the nerve-roots pass indicate that this is the first lumbar segment of the cord. The shape of the section is flat, as the result of the escape of fluid from its interior, owing to tearing of the pia. The anterior median fissure is normal; in the posterior median line a small fibrous septum composed of pia extends inwards almost to the central canal, from which it is separated by a glial commissure connecting the two halves of the cord. In sections at the upper part of this block of tissue, 1 mm. above the section photographed, this adventitious pial septum disappears, and the posterior glial septum is normal. It therefore represents the beginning of the abnormal adherence between the posterior wall of cord and the meninges, which is so much more intimate lower down. The central canal is very large and flattened antero-posteriorly, due to the escape of fluid. Anterior horn cells are well formed though few in number, but it must be remembered that the cord was pulled out by traction from the sac below, so that the cells in a given section would be less numerous than when the tissue was normally concentrated; and the total number of cells in each segment is not necessarily reduced. In certain of the sections from this area anterior nerve-roots emerge in the region indicated in the photograph. Posterior horn cells cannot be distinguished; the position of entering posterior root fibres is shown. Myelinated posterior columns are present, and there appears to be a small lateral cerebrospinal tract and a number of other myelinated fibres, some of which may represent descending tracts. They are not sufficiently well differentiated to name them with accuracy; probably many belong to the fasciculi proprii. The median part of the posterior column, usually occupied by the long fibres from the posterior roots, contains less myelinated fibres than the lateral part. This part is composed of the lower of the ascending posterior root fibres, and in this specimen many of these are caught in the meningeal sac and never reach the cord. Throughout the section there is a preponderance of glia cells and a considerable number of lymphocytes.

Section B (fig. 18, B):—Dilated cord just below its entrance into the sac. The nerve roots which originate here pass into the fourth lumbar foramina, so that this represents the fourth lumbar cord segment. The cord here was contracted into a flat, narrow band, but when the section was cut it stretched widely, so that it was evident that it had been greatly distended with fluid. The attempt to preserve its circular form was a failure and the photograph shows only a small portion of the anterior region. The pia over all the section is thickened, and posteriorly it blends with a dense dura-arachnoid, the layers

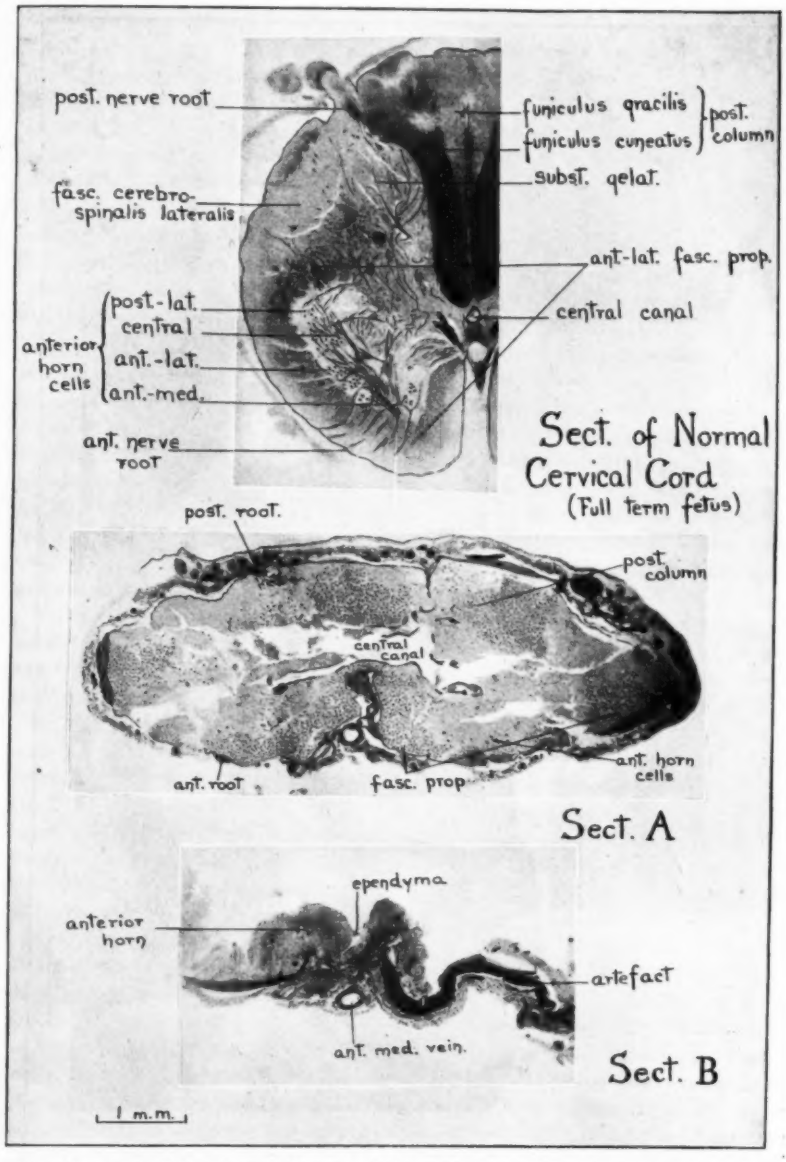

FIG. 18.—Case V, lumbo-sacral cystic hydromyelocele. Photomicrographs of sections A and B made at levels indicated in fig. 17. Upper section is from a normal cervical cord of a full term fœtus for comparison, under the same magnification as other photographs.

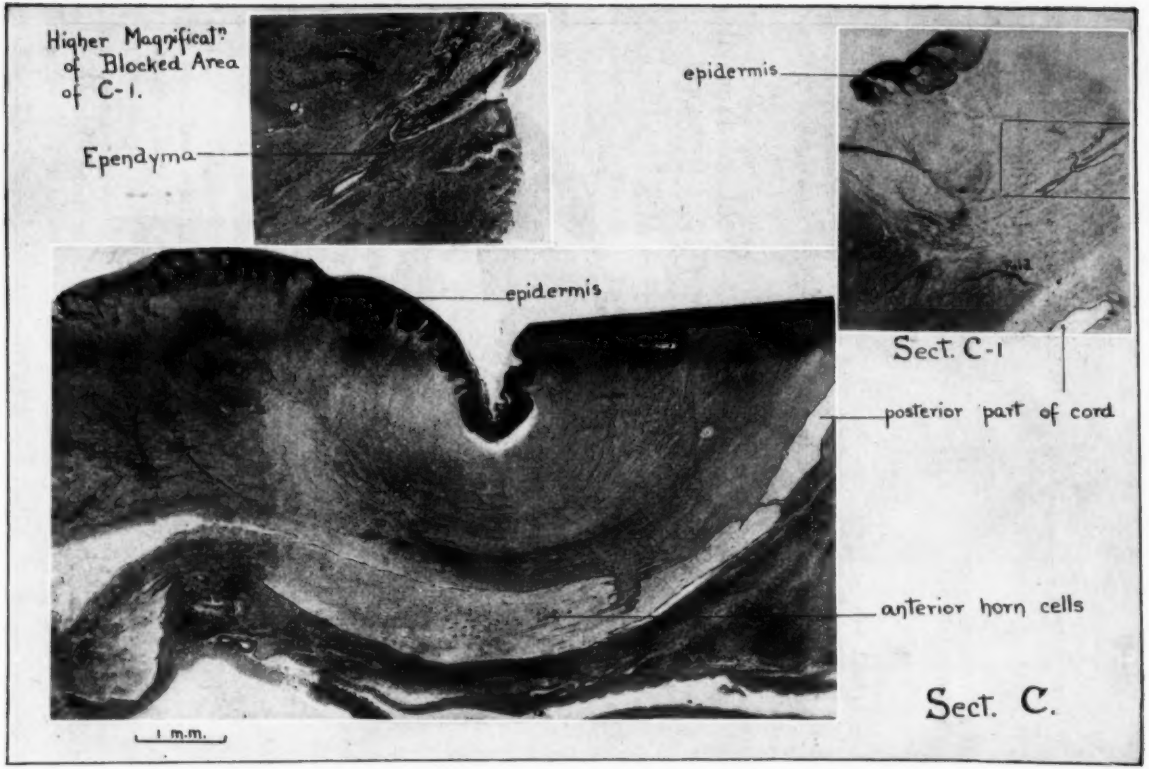

FIG. 19.—Case V, lumbo-sacral cystic hydromyelocele. Photomicrographs of Section C, made at level indicated in fig. 17. Section C-1, from the lateral pocket. Fold in section coincides with that in Section C.

of which are indistinguishable and infiltrated with inflammatory cells. This dural layer blends posteriorly with the subcutaneous fat in the neck of the meningocele. The anterior mid-line is indicated by a short prolongation of the pial layer inward and a large anterior median vein, but there is no true anterior median septum. Near this many bundles of myelinated nerve fibres (anterior roots) are found lying in the pia where it blends with the dura of the sac. Emerging anterior root fibres are found near the median line, but posterior roots could not be seen entering the cord. Within the pia there is a small layer of nervous tissue. This is somewhat thicker near the anterior median line, and in this region there is a diverticulum from the general cavity which appears to be imperfectly lined by ependymal cells. On either side of the median line there are a number of vacuolated cells with pale nuclei, which possibly may be anterior horn cells which have undergone degenerative changes. No other nerve-cells are present; the layer of tissue is an indiscriminate mixture of partly myelinated fibres and neuroglia with a few small vessels and occasional lymphocytes, but with no landmarks by which one can recognize even its regions with accuracy. Except for the few doubtful ependymal cells mentioned above the central cavity is without definite lining, and is bounded by the degenerated nervous mass which has been described. It is impossible from this section, therefore, to say whether the cyst is a dilated central canal or an adventitious cavity, though it seems probable from the sections above and below that it is a dilatation of the central canal.

Section C (fig. 12, C).—Wall of sac and attached end of the cord, with the lateral pocket of the hydro-myelocele. The nerve-roots from this portion of the cord are those of the first sacral nerve, indicating that this represents the first sacral segment of the cord.

The surface epithelium is fairly thick and has a few papillary processes; hair follicles and skin glands are lacking, as is the subcutaneous fatty layer. Beneath the epithelium are dense bands of fibrous tissue, the fibres of which run transversely to the long axis of the cord. Below this fibrous layer is a layer of looser, more delicate connective tissue, considerably infiltrated with round and polynuclear cells. Laterally this layer extends about 5 mm. from the middle line, and there splits into two leaves, of which one passes laterally to merge with the dura-arachnoid lining of the sac. The other passes medially, and with the corresponding leaf of the opposite side forms a sheath for the attached end of the cord. The whole of this layer, which represents pia, is densely infiltrated with inflammatory cells. At the middle line the anterior layers project upwards towards the roof of the sac, forming an imperfect anterior median fissure in which the pia is distinguished by its great vascularity. The cord tissue enclosed between the layers of this pial sheath bears little resemblance to normal cord. The inflammatory connective tissue which bridges the gap between anterior median septum and sac roof divides the nervous tissue into two masses; no nervous elements can be recognized connecting these across the median line. No trace of central canal is present. In each lateral nervous mass certain nervous structures can be determined. The

photograph (fig. 19, C) shows but one lateral half and a very small portion of the other, with the median anterior septal mass of connective tissue already described. It will be seen that the cord is not rounded, but is represented by a flattened band, each half of which is roughly divided into two regions. In the more medial of these anterior horn cells normal in size and shape are easily recognized. Lying between them are many glia cells, and many fibroblasts and inflammatory cells. In the more lateral of the nervous masses no nerve cells can be distinguished, the mass consisting of glia infiltrated with a few inflammatory cells. No myelinated fibres can be found in any portion of the cord tissue, save one or two delicate scattered fibres in the region of the anterior horn cells. In certain of the sections from this region anterior root fibres emerge in the position indicated in the photograph. No posterior root fibres can be found entering the cord tissue.

Passing laterally to the outer limit of the posterior region of the cord (i.e., the lateral glial masses), separated from these by the fused dura-arachnoid lining the interior of the sac, and lying near the integumentary epithelium but separated from it by connective tissue, is the lateral pocket of the dilated proximal portion of cord. (Cf. fig. 17, in which a probe is passed into this pocket, and the description of the gross findings.) This pocket is shown in C-1 on fig. 19. It is lined with a perfect layer of ependymal cells, surrounded by a narrow zone of glial cells, among which there are a few myelinated fibres. In the more distal sections from this block the pocket ends blindly in a small glial mass; it never makes any direct connection with the lateral cord masses at this level. As one passes caudalwards from the end of the cord the sections show the same general characteristics, but the anterior horn mass becomes less definite, and the lateral (posterior) masses are separated into smaller portions by strands of connective tissue. They spread also more laterally, and 2 mm. distal to the section shown in the photograph are so attenuated and mingled with connective tissue that little neural character remains.

Section D (not photographed).—Taken 5 mm. below the level of the block cut for Section C, through the wall of the sac where cord tissue has apparently blended with it.

Here there are a few imperfect hair follicles and sweat glands; no subcutaneous fat is present. The tissue below the epithelial layer is denser connective tissue than is normal, and towards the interior of the sac it blends with the dura arachnoid and with an imperfectly differentiated pia, between the layers of which are nerve bundles. These are numerous and conspicuous, but examination shows that they contain but few myelinated fibres lying between connective tissue and inflammatory cells. The apparent large size of the nerve roots seen by the naked eye is therefore misleading. A small glial mass is found at the median line, but this contains no true nerve cells nor central canal. The surface epithelium immediately above this glial mass shows an unusually deep slender papillary process of elongated spindle-shaped cells; but no connection between this and the glial cord mass can be demonstrated, as they are separated by bundles of connective tissue.

General Discussion of Cases III, IV, and V.

The points of interest in these three cases are discussed together because clinically and anatomically they are closely allied.

(1) The lesion in all is lumbo-sacral and had the clinical appearance of a pure meningocele, though in two of the cases ulceration of the sac wall might have led to a suspicion of involvement of the cord.

(2) In each the cord is bound to the wall of the sac by the segment corresponding to the highest vertebral segment which is cleft.

(3) The collection of fluid has drawn the cord above the proximal affected segment down into the sac, so that higher segments are influenced by traction.

(4) Hydromyelia in cord segments above the lesion is present in each case, extending as high up as the cord was removed at autopsy in two cases and as high as it could be observed at operation in the case without autopsy, and for an unknown distance above this. In Case V this is most marked and is complicated by the adherence of the intrasaccular portion of the cord to the sac wall, causing a secondary myelocystocele.

(5) The cord at the level of the point of attachment in each case is cut off from both ascending and descending nervous connections by the adherence of cord tissue and nerve roots to the sac wall, so that even before operative interference the lesion amounted to an almost complete transverse lesion of the cord at this point.

(6) Segments of the cord lying distal to the segment attached to the sac are imperfectly developed and partly destroyed by the adherence to sac wall; and there is evidence to show that they have never been closed but represent a persistent neural groove which has been overgrown by adhesions and integument.

In Case IV this is capable of direct proof, as is shown in fig. 14, Section C, where partly differentiated epithelium of mixed neural and integumentary character is found on its external surface. In Cases III and V the overgrowth of skin epithelium has obscured the defect to a greater extent, but the lateral spreading of the nervous tissue, the absence of central canal and the position of nerve-roots with reference to the ribbon-like band of cord tissue, indicate that in these cases also the initial lesion has been a failure of closure of the lower sacral segments. Later, the meningeal layers have grown over the defective cord, and to a less marked extent over the open medullary ribbon in Cases I and II; and still later the skin epithelium has covered the whole, and the adhesions so formed have destroyed any vestiges of

ependymal cells which may have been present. It has already been noted that in complete lesions involving the whole of the neural tube (Case II) there is a tendency for skin to grow over the lower part of the defective area; the tendency of the skin epithelium even in the adult body toward growth is clearly shown in all granulating superficial wounds.

The accumulation of fluid in the meningeal part of the sac is always in these cases a secondary occurrence, and accounts for the dragging of the normal cord outwards. The accumulation of fluid in the cord tissue itself is a result of its abnormal adhesion. No satisfactory explanation of the collection of fluid in either the meningeal or the medullary sacs has yet been given. It cannot be even suggested from a study of these cases alone, but involves the consideration of the whole subject of the normal production and absorption of cerebrospinal fluid and all the possible abnormalities thereof.

CASE VI.

Myelocele rachischisis completa restricta of Class 3, A.

Specimen No. 802, University of Texas Pathological Museum.

The specimen is of a full-term white female, length 38·5 cm. from vertex to coccyx. The external appearance is normal except for a considerable degree of hydrocephalus and a lumbo-sacral spina bifida. The head had been lacerated to promote delivery, and there are forceps marks upon the thighs. The body is somewhat degenerated, but there is no evidence that death had occurred before the beginning of labour. The degeneration appears to be the result of imperfect preservation, as the body had evidently been allowed to dry, and then had been placed whole in fixing fluid without any injection. For this reason the examination is in some respects unsatisfactory.

Dissection.—The head measures 49 cm. in circumference, but there has been some collapse which cannot be accurately estimated. The brain has been entirely destroyed by stuffing the cranial cavity with cotton, so that only a small irregular mass of tissue remains at the base, which cannot be identified by the naked eye, and its preservation is such that microscopical sections are of no value. The exposure of the vertebræ from behind shows that all the cervical, all the thoracic, and the first three lumbar vertebræ are normal. The laminæ of the fourth lumbar meet in the median line, where they are fused by a cartilaginous union, but they do not possess any spinous processes. The laminæ of the fifth lumbar are directed towards the median line, but are separated from each other by a space of 7 mm., which is bridged by a band of connective tissue. The sacral laminæ flare outward, and are somewhat smaller than normal. The coccyx appears to be normal.

These lower vertebræ from the fifth lumbar to the last sacral are covered

externally by the parchment skin of the myelocele, of which the external appearance is shown in fig. 20, B. It will be described in detail later.

Dissection of the spinal cord and meninges above the level of the fifth lumbar vertebra shows that the meningeal layers are normal, but the dural sheath is somewhat collapsed, the epidural space being occupied by a gelatinous exudate, and the vascular and fatty tissue normally found here is reduced in quantity. The spinal ganglia are normal in size and position in all this region of the cord, but the dural sheaths of the spinal nerve roots, which should incline very slightly caudalward in the lower thoracic and lumbar areas, have a transverse direction. On opening the dura-arachnoid the cord is found to be soft and poorly preserved, so that only with great care in handling can

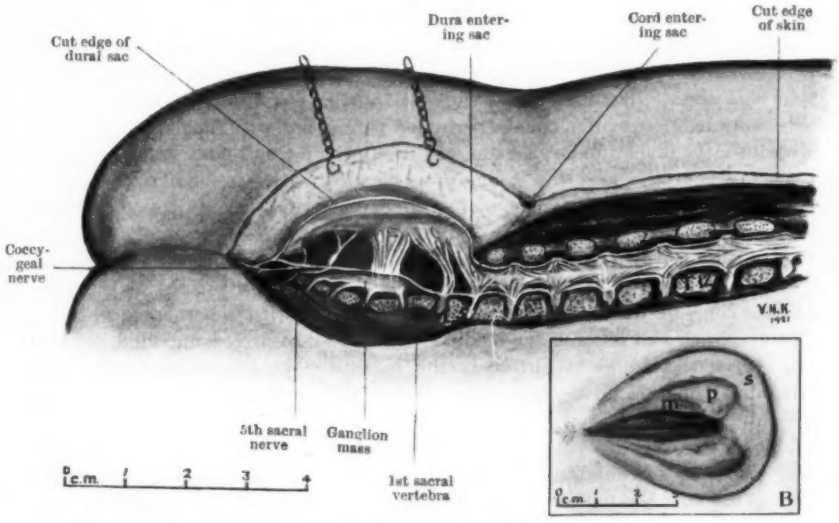

FIG. 20.—Case VI, lumbo-sacral myelocele. Dissection of right side of myelocele. B, external appearance.

the nerve roots be traced. Those roots from the cervical and upper ten thoracic segments are normal in direction (cf. fig. 5, B), the tenth thoracic roots arising from the cord at the level of the body of the ninth thoracic vertebra. From this point they tend to lose their downward inclination, and present the relationships shown in fig. 20, A, that is the eleventh thoracic roots arise from the cord at the level of the tenth vertebral body; the twelfth thoracic roots from that at the level of the eleventh and twelfth vertebræ; the first lumbar roots from the cord at the level of the first lumbar vertebra: the second lumbar from the cord at the level of the second and third lumbar vertebræ; and the third lumbar roots from the level of the third and fourth lumbar vertebræ. The fourth and fifth will be considered in the description of the

myelocele. The condition of the cord is not such that any further examination can be made; it appears to be considerably smaller than normal, but definite evidence of collapse of a cystic condition remained.

Myelocele.—The parchment skin of the myelocele is somewhat wrinkled but flat, and there is no sign of a previous distension with fluid. It measures 35 mm. in transverse and 45 mm. in vertical diameter, and extends from the level of the fifth lumbar vertebra to that of the fourth sacral. At the level of the fifth sacral in the median line the skin is normal; a small tuft of fine hair is present here, but this is no more than is frequently found in this region in normal infants. The character of the wall of the myelocele is of considerable interest. As is seen in the drawing (fig. 20, B), it is pyriform with the apex directed caudalward. The upper part is rather sharply marked off from the surrounding skin by a groove, which disappears in the lower third of the "pear." Within this for a distance of 12 mm. at the broad end, and 10 mm. at the narrow end of the sac, the skin (s) is normal in appearance, except that it is slightly elevated above the level of the surrounding skin. Within this there is an irregular zone of wrinkled parchment skin, delicate in texture, without fatty layer; under a hand lens it shows fine hair and pores. At the upper part of the sac this zone (p) is blended with a very narrow zone of membrane (m), without evidence of epithelial covering, i.e., a meningeal layer; but at the lower part there is no such zone. Down the mid-line of the sac lies a band of brown tissue (n) which has the appearance of being covered by dried blood. This merges above and below into the skin surface of the peripheral zone of the sac, but laterally it is fused with the meningeal zone. The specimen had become dry before it was placed in preserving fluid, for this band of tissue, which is obviously the medullary groove, is contracted and hard, but there is no degeneration of this region which interferes with the dissection of the lesion.

Dissection (fig. 20).—The myelocele was surrounded by a circular incision and the skin surrounding it dissected up with its subcutaneous layer and turned towards the median line. At the inner margin of the peripheral zone of the skin (fig. 20, B) the subcutaneous fatty layer disappears and a meningeal sac is found. The limits of this correspond very closely with the outer border of the flaring sacral laminæ, but caudally it extends no lower than the fourth sacral vertebra. On cutting through the lateral margin of this and reflecting it, the dorsal wall of the sac is found to be composed of a fusion of dura and arachnoid with surface epithelium, and to pass medially into the medullary ribbon. The ventral wall is composed of dura and arachnoid, and lies in contact with the bodies and exposed dorsal surfaces of the flaring laminæ of the sacral vertebræ. In order to study the relationships of the medullary ribbon more carefully, the bridge of connective tissue arching the gap between the fifth lumbar verebral laminæ was dissected away and the pedicle of this vertebra cut to show the foramen for the fifth lumbar nerve. The flaring laminæ and spines of the sacrum were also removed, exposing the posterior sacral foramina.

At the level of the fifth lumbar vertebra the dural layer of the sac passes under the fibrous arch into the spinal canal. The opening in the dura was continued from the sac below to that already made in the sheath of the cord above, exposing the spinal cord as it passes from the canal into the upper part of the sac roof, where it becomes continuous with the medullary ribbon. In fig. 20 this dissection is shown on the right side. It will be seen in the drawing that the traction of the reflected area of the sac has pulled the cord and medullary ribbon out of the vertebral groove in which they lay, and the length of the closed part of the cord, from the neck of the sac to the roof, is somewhat exaggerated. The fourth lumbar nerve roots arise partly from the cord in relation to the fourth lumbar vertebra (above the sac) and partly from the closed cord as it passes under the fifth lumbar fibrous arch to the medullary ribbon. The fifth lumbar root arises from the proximal part of the medullary ribbon; its ganglion is normally situated. The roots of the upper four sacral nerves of the right side are grouped together so closely that no absolute differentiation between individual nerves, nor between anterior and posterior roots can be determined. This clump of fibres passes through the dural floor of the myelocele, and into an elongated mass of nervous tissue enclosed in a prolongation of the dural sheath, lying in the groove representing the open sacral canal. From this, nerves can be traced to the upper four posterior sacral foramina. It therefore represents the upper four sacral ganglia fused into one mass. Certain of the proximal radicles of this clump appear to pass medial to the ganglionic mass and directly into the anterior foramina, but the tissues are so delicate that this cannot be definitely proved without more destruction of the specimen than seems justifiable. From the medullary ribbon distal to the clump of roots described, two delicate roots, on one of which there is a small ganglionic mass lying *within* the dura, pass out as the fifth sacral nerve. Still more distally a delicate strand passes down from the ribbon; this probably represents the coccygeal nerve, though it is too delicate to be definitely identified, and no ganglion could be found upon it. Distal to this the medullary ribbon, which has narrowed to a sharp point, passes into a slender fibrous strand and by this is connected with the dural floor of the myelocele, and through this to the coccyx and subcutaneous tissue over it.

On the left side the condition is similar except that the first sacral root has a normal ganglion, and anterior and posterior radicles can be differentiated; the ganglia of the second, third and fourth sacral are grouped into one mass, as on the right side. The fifth sacral has a well-developed ganglion occupying its normal position outside the spinal sheath of dura. It should be mentioned that there is some doubt as to the ganglionic character of the intradural mass on the right fifth sacral. It is much smaller than normal, and indeed the roots on this side are much smaller than the corresponding roots on the left side; and very close to the medullary ribbon. There was no other ganglion on this nerve-root; for various reasons no section of this minute body was made.

Microscopical examination.—An attempt to procure material for examination

of the cord above the lesion was an absolute failure. The tissue was so degenerated that nothing could be done with it. The tissue of the myelocele was hard but well preserved, as was the ganglionic mass. The sections were taken from the fifth lumbar and first sacral segments (fig. 20). It seemed best not to destroy the specimen for museum purposes and therefore no serial sections were made below this level.

Section A (fig. 21, A).—Just below the attachment of the cord to the roof of the myelocele, representing the level of the first sacral segment of the cord. On the right side the skin surface shows many sweat glands and numerous small hair follicles which are more deeply situated than normally. This zone of skin is that marked " n " in fig. 20, B. It passes rather suddenly into a fibrous layer " m," apparently meningeal, but covered by a thin layer of stratified squamous epithelium which has no papillæ nor other integumentary structures. This zone in turn passes medially and the fibrous layers are fused with the pia which lies ventral to the ribbon cord. The layer of surface epithelium ends rather abruptly on this side of the specimen in a mass of epithelial and blood cells which separates it from the outlying (posterior) portion of the ribbon cord. One small mass of glia is found in the fibrous tissue just lateral to this hæmorrhagic area, and is covered by the surface epithelial layer. On the opposite (left) side the relations are somewhat different. The surface epithelium passes medially over the outlying area of ribbon cord and there terminates abruptly, and lateral glial masses of considerable size are found beneath the epidermis, separated from it by a thin layer of fibrous tissue which apparently represents corium. Non-myelinated posterior nerve-roots approach the glial masses on each side; on the right they are situated just beneath the hæmorrhagic zone; on the left, they appear to enter the cord where the surface epithelium terminates.

The structure of the medullary ribbon does not differ materially from that of the ribbon cord in Case I. Anterior horn cells are well developed; anterior nerve-roots are present but are not myelinated. At the middle line there is a depression corresponding with the central canal, and beneath it a narrow anterior commissure. This depression and the surface of the ribbon contiguous to it are covered by ependymal cells. The anterior white matter lies median to the spreading anterior grey horns. All of this region of the medullary ribbon is œdematous, and there are great numbers of small blood-vessels coursing through it. The majority of these are in definite trabeculæ of connective tissue. Laterally there remains but little evidence of the posterior portion of the cord, except the glial masses already noted as lying lateral to and separated from the main medullary tissue. The small posterior portion not separated from the main ribbon appears to be made up of glia and possibly nerve-fibres without any evidence of posterior horn cells. There are no myelinated fibres anywhere in the section.

The sections 2 mm. caudal to this show no great change except the gradual decrease in the number of anterior horn cells and the increase in the vascular invasion of the cord structure. The isolated glial masses noted

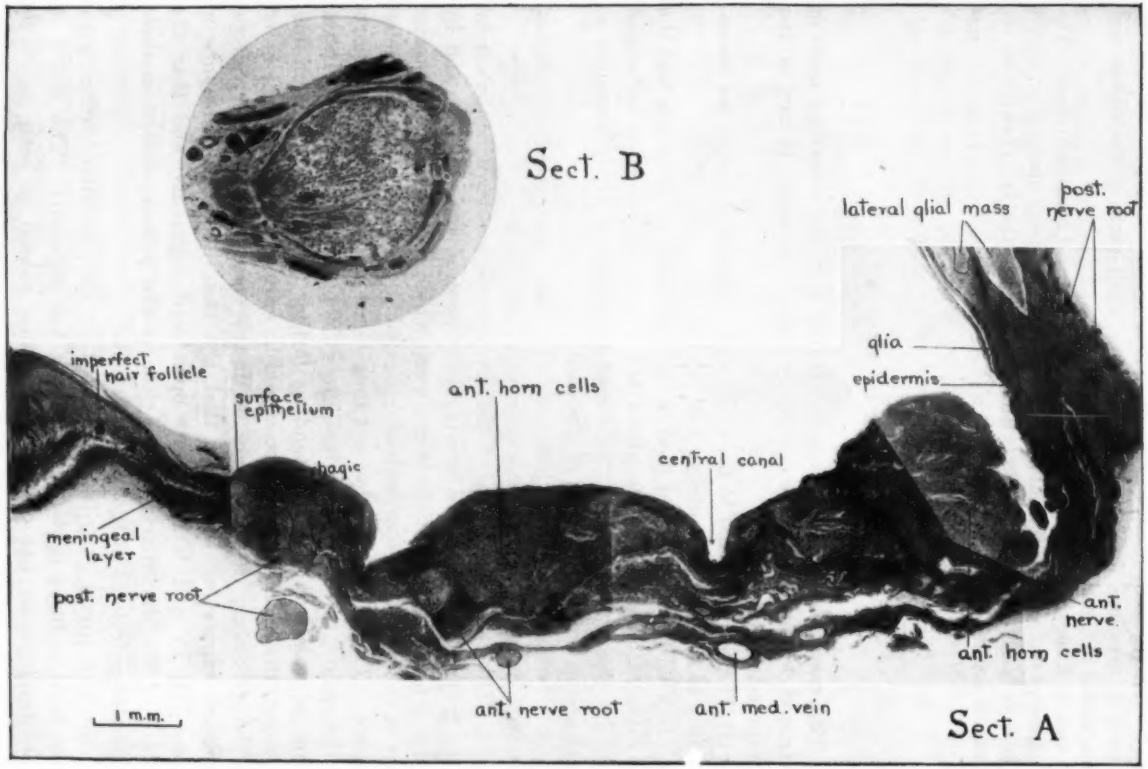

FIG. 21.—Case VI, lumbo-sacral myelocele. Photomicrograph of section through upper part of myelocele. B, section through fused spinal ganglion.

in the higher sections disappear in the fibrous tissue. The posterior portion of cord is therefore represented only by the small parts of the ribbon cord lying lateral to the motor cell group.

Section B (figs. 20 and 21, B).—Section of the fused ganglionic mass. The structure of this mass is typical and confirms the naked-eye observation that it represents fused root ganglia. It is abnormal only in the fact that the nerve-fibres are non-myelinated.

Discussion of Case VI.

This case corresponds in many features with the preceding cases of restricted lesion, and throws light on certain obscure points in the interpretation of these.

(1) The cord is bound to the roof of the sac by the segment corresponding to the highest vertebra that is cleft.

(2) There is no excess of fluid in the myelocele or meninges, and the direction of the nerve roots above the lesion, therefore, is influenced only by the attachment of the cord; they pass to their foramina at right angles to the long axis of the cord.

(3) Hydromyelia and hydrocephalus are associated, indicating defective development of the entire medullary tube.

(4) The neural ectoderm of the involved segments, which is spread open in the form of a groove, is partially covered by epidermis and by connective tissue, so that the lateral part, which represents the posterior part of the cord, is to some extent separated into isolated neuro-epithelial masses. The overgrowth has not progressed farther than the outskirts of the ribbon, so that the original groove is plainly discernible. In the event of this overgrowth extending farther towards the median line, however, the resulting condition would be entirely similar to that found in the preceding cases. There is in this case, therefore, very strong evidence supporting the belief that the band-like cord substance in Cases III, IV and V represents open cord segments, and that the failure of the medullary tube to close is the primary lesion in these restricted defects as in the more extensive.

(5) The spinal ganglia are affected by the medullary defect, since they form a fused mass in certain of the segments. The defect in their development has not, however, either caused or been caused by defect in the corresponding vertebral segments, since these are segmentally normal even though they are incompletely fused dorsally.

Case VII.

Meningocele—rachischisis incompleta restricta of Class 1, B.

History.—D. M., female, aged 11 months, John Sealy Hospital.

No family history of deformity nor nervous lesion. Child is healthy and well-developed except for the presence of a lumbo-sacral tumour. Control of bladder and bowels appears to be normal. Baby presents a small congenital tumour covered by parchment skin, about 1½ in. in diameter, occupying the sacral region. It is tense, its surface is unbroken, and is slightly painful on

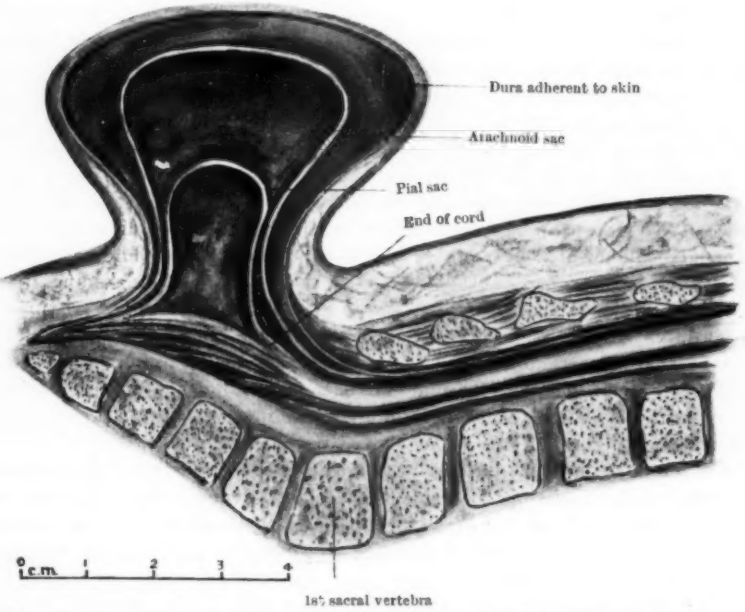

Fig. 22.—Case VII, meningocele. Posterior surface of cord shown as seen at operation. No facts available regarding nerve roots.

pressure. Operation, by Dr. J. E. Thompson, September 18, 1918, ether anæsthesia. Transverse incision made above and below tumour, and outer parchment skin dissected up, opening the sac. Within the parchment sac two others were found, lying one inside the other, as represented in fig. 22. The wall of the second sac was very thick and shining, and was thought at the time of operation to represent dura; fluid withdrawn from this sac gave a positive "glucose reduction." The third sac also contained fluid, but this was not tested for reduction. It was thinner and had at its upper end a small mass of spinal cord tissue. This sac was typical pia, but slightly thicker than usual.

It was opened and its walls sutured over the *cord* (not cauda equina alone) which was found to lie inside it; the portion of cord lying in its proximal portion was not disturbed. The second sac, which was thought to be dural, was partly dissected away, and its edges sutured; and the parchment skin of the external sac was removed until normal skin was reached and this was finally sutured. Convalescence was ideal, and the baby was dismissed from the hospital, September 26. Later history: February, 1921, the mother reports that the child's general health is good and that she is bright mentally. She began to walk at the age of 18 months; at first she had a tendency to "turn the feet in," but this is improving. She has very good control of the bladder, but not of the bowels.

Discussion of case.—Unfortunately this case occurred before the writer's interest in spina bifida had been awakened, and the small portions of the meningeal sacs which had been dissected away in the operation were not preserved. The diagram shown in fig. 22 is reconstructed from a drawing of the sac layers made at the time of the operation. In the light of the conditions in other cases it is probable that the sac thought at operation to be dural was a thickened arachnoid sac, and that the inner sac was composed of the outer layer of the pia. The outer parchment skin was lined by a glistening membrane and filled with clear fluid, and this doubtless represented the fused integument and dura, as in other specimens described. The thickening of the arachnoid of the inner sac, which led to the misconception at the time of operation, is entirely in accordance with observations on Case IV, in which a partial transverse septum of arachnoid is found. The position of cord tissue in relation to the upper part of the innermost sac clearly indicates that this is pial. The drawing has been labelled according to this interpretation in preference to that made at the time of operation.

The feature of peculiar interest in this case is the presence of cord tissue in the floor of the upper part of this sac. The nervous tissue observed was spinal medulla and not the nerve roots of the cauda equina. It is obvious that no detailed examination of this nor of the cauda equina could be made. This much, however, was discovered, that the cord extended as far as the floor of the meningocele, i.e., as low down as the fifth lumbar vertebra, though it should end at the second. This indicates that in this case, in which apparently no structures except the meninges (mesoderm) were involved, there was at some time in the development adherence of ectoderm sufficient to bind the neural tube down in the vertebral canal. This is a feature of many of the "simple meningoceles" which has not received due consideration in the study of operative results, and accounts no doubt for the frequent lack of control of bladder and bowels in these patients.

General Considerations.

With a study of specific cases in mind, the review of the literature and especially the clinical literature can be more readily appreciated.

For this reason all statistical and practical considerations have been deferred to this place. Neither time nor opportunity has sufficed for a complete study of all the available writings on the subject, yet it is hoped that this survey, in spite of its incompleteness, will not be without value. All matters which do not have a direct bearing on the anatomical study presented have been omitted.

Statistical Summary.

Frequency.—The Report of the Committee on Spina Bifida of the London Clinical Society, presented to the Society in 1885, cites the following frequency statistics: "Dr. Demme found 57 cases of spina bifida in 36,148 children; Chaussier records 22 cases among 22,293 children in the Paris Maternité." Harrar, in 1916, found 59 cases of spina bifida in 91,600 births in the Lying-in Hospital in New York. Grouping these figures we have an incidence of 1 in 900 births. Joseph gives the frequency of "spina bifida with tumour" as 1 in 1,000 births. Both these percentages omit the cases of spina bifida occulta, since these are not discoverable in the infant except in very rare cases. S. N. Clark gives the percentage of spina bifida occulta as 5 per cent. of all cases, but he evidently refers to cases giving rise to nervous symptoms. The mild varieties in which cleft of the laminæ or of the spines alone occurs without symptoms of pressure on the cord are fairly frequently encountered in the dissecting room. No facts regarding the percentage of all cases which are sufficiently limited to be of surgical importance are available.

Locality.—In 385 operative cases treated by excision, collected by J. E. Moore in 1905, the locality is given as follows: 23 per cent. sacral; 34 per cent. lumbar; 24 per cent. lumbo-sacral; 4½ per cent. thoracic; 9½ per cent. cervical; two cases were occipital. This represents the localization of the restricted (operable) variety of lesion only, but it is in such cases that locality is of practical importance.

Type of restricted lesions.—Unfortunately Moore does not give the percentages of different types of tumour encountered in his collection; doubtless in many of the cases he collected there was no specific information regarding this feature. Fenner places meningoceles at 10 per cent. and meningo-myeloceles at 70 per cent. to 80 per cent. of the cases. In a total of 170 cases in which accurate anatomical data are given, collected by the writer from the literature cited in the bibliography appended to this paper, the percentage is as follows: 7 cases (4·1 per cent.) spina bifida occulta (with symptoms); 4 cases (2·3 per cent.)

"meningoceles with adherent cauda equina"; 36 cases (21·1 per cent.) pure meningoceles; 120 cases (70·6 per cent.) myelo-meningoceles; and 3 cases (1·7 per cent.) syringo-myelo-meningoceles. As the meningoceles only in this series presented no nervous lesion, this indicates that 78 per cent. of all restricted cases involve the cord or its nerve-roots to some extent. From the point of view of operability and functional result this is a matter of prime importance.

Complications.—In non-viable cases unassociated anomalies—hare-lip, ectopia vesicæ, non-paralytic club-foot and other more widespread abnormalities—are very common. In viable cases they are less frequent, but still sufficiently so to call for comment.

Nervous complications are of even greater frequency. Among 359 cases collected by the London Clinical Society, in which the complications are stated, 46 had hydrocephalus. These are cases in which the patients had restricted lesions. Harrar in the records of 68 cases in the Lying-in Hospital found 23 cases of primary hydrocephalus and 10 developing hydrocephalus following operation. The greater number which he found are doubtless due to the fact that his records include all cases observed, whether viable or not.

No facts regarding the incidence of hydromyelia are available. From my own very limited experience it appears to occur in a high percentage of those cases in which the cord is involved in the lesion, whether there be hydrocephalus or not. Thus in Cases I and VI there was hydrocephalus and hydromyelia above the open cord segments; in Cases III, IV and V there was hydromyelia without hydrocephalus. Information regarding the condition of the cord in the single case of meningocele reported (Case VII) is necessarily lacking. The small proportion of restricted cases which show sufficient dilatation of the cord to fall into the class of syringo- (or hydro-) myelo-meningocele, represents, therefore, only an exaggeration of a fairly frequent condition. Further investigation along this line is urgently needed. Post-mortem examination is not always essential to this, since careful examination of the cut end of the cord at the time of operation on cases with attached cord will reveal any considerable dilatation which may be present, and while the extent of this lesion upward may remain uncertain, it appears to be practically certain that a dilatation which is plainly visible at this point involves a considerable number of segments above. All cases in which complete autopsy findings can be obtained should be investigated with reference to this feature.

Paralyses of the sphincters or of the legs, and loss of sensation

over areas supplied by nerves involved in the lesion, are encountered in the exact proportion in which one finds involvement of the cord in the lesion, and are a direct result rather than a complication of the disease.

Course of the disease.—A large proportion of untreated cases die within a few months. Thus of 649 deaths due to spina bifida, occurring in England in the year 1882, most of them in untreated patients, 612 were in the first year of life. Of 68 cases reviewed by Harrar (59 born in the Lying-in Hospital and 9 others sent in for operation) 7 were stillborn, and 29 died untreated within a few weeks. The other cases of his series were submitted to operation. Of 49 fatal cases of untreated restricted lesion collected by the writer, in which the cause of death is definitely stated, 14 died of marasmus, 7 of intercurrent infection, 2 of hydrocephalus, 23 of rupture of the sac, 3 of convulsions (i.e., meningitis). Accurate statistics of such untreated cases are very hard to obtain since untreated cases are but rarely recorded. In but a very small proportion even of the mild defects is there hope of recovery without operative interference, yet in a few of the less severe cases spontaneous cure occurs. In the 60 untreated cases recorded by the London Clinical Society, 14 cases (23·3 per cent.) were cured in the following manner: in eight there was a gradual shrinkage of the sac; in one it ulcerated and oozed for some time; in four it burst and later shrank away. The shrinkage of small tumours in this way probably accounts for a certain number of cases of spina bifida occulta, while others may be accounted for by a similar reduction of the tumour in intra-uterine life.

Operative mortality.—In Moore's series there was 27 per cent primary mortality, with an additional 7 per cent. within three months after operation, bringing the total to 34 per cent. When one considers that the cases which are operated upon are all selected cases, this primary mortality is exceedingly high; moreover, a secondary mortality is to be expected, apart from operative interference. Moore considers that "if all cases had been followed and reported, the probability is that the mortality at the time of, and a few months subsequent to, operation would be fully 50 per cent." In view of this he considers that operative interference in children under 5 years of age is scarcely worth while, since it appears neither to reduce the natural death-rate nor to be attended by great functional success. On the other hand he takes the position that children who have survived to that age may be submitted to the risk of operation.

As opposed to this view there is the great danger already alluded to, of rupture and ulceration of the sac. In 117 untreated cases collected from the appended bibliography, rupture of the sac occurred 27 times. In 97 of these cases in which the character of the sac is recorded, there was ulceration in 24. In the five restricted cases considered in this report, there was rupture in one, gross ulceration of the sac in two, and microscopical evidence of inflammation in the shape of polynuclear and round cell infiltration in four. One sac was not examined microscopically. In the case in which Morton's fluid was used death occurred immediately upon the injection, so that the inflammatory exudate was present prior to this treatment. Harmer found ulceration in 64·7 per cent. of his 34 cases. He further points out that he has found rupture of the sac in patients a few hours old, and suggests very early operation because of this danger and that of ulceration with subsequent meningitis. In view of the fact that few untreated cases are recorded it seems probable that these complications occur even more frequently than the figures would lead one to suspect. The primary operative mortality, so largely due to infection, might be materially decreased by very early operation, even though the secondary mortality, which depends mainly upon hydrocephalus and marasmus, be correspondingly increased. There appears to be no reason to consider that operation increases the percentage of hydrocephalus, in view of the large percentage occurring without interference and the number of cases that are accompanied by hydromyelia. It must be borne in mind in considering this that the majority of successfully operated cases (i.e., those which do not succumb to the immediate effects of operation, as shock, infection, &c.) live longer than do untreated cases, and therefore a higher percentage die of hydrocephalus which would otherwise have died of the meningocele itself (rupture, meningitis, &c.). Many surgeons, however, recognizing the high incidence of hydrocephalus, prefer to wait some months for its development before undertaking an operation which they feel may be useless.

Theoretical Considerations regarding Surgical Procedure.

Operability.—The question of operation upon cases with associated hydrocephalus, paralyses, &c., must remain largely a matter of individual opinion. It is purely from the point of view of the anatomical facts that I propose to discuss it. There can be no doubt that pure meningoceles should be operated upon, and in view of the possibility of

ulceration or rupture of the sac they should be treated early. Moreover, shock is almost certainly less in operations upon the spinal cord of young infants than in older children. Spontaneous cure is not to be expected in the great majority of cases, and the risks run by awaiting it are too great. In the cases in which there is some doubt as to the presence of nerve elements in the sac, evidences of paralyses, especially of sphincters, and anæsthesia round the anal margin or on the back of the thighs, are of value. Ulceration of the sac wall, a thickened band down the middle of a thin sac wall, and a vascular granulating surface with umbilication, are valuable diagnostic indications of adherence of the cord. The presence of skin covering the whole of the sac does not rule out myelocele. It must be borne in mind that meningoceles are infrequent and myelomeningoceles frequent, but that but few meningoceles have broad bases. Transillumination of the sac has been suggested for finding the presence of nerve roots, but it seems possible that this might lead to error, as adventitious meningeal adhesions sometimes occur. In contemplating operation on those cases in which cord is known or suspected to be present, one should consider that in this type spontaneous cure is practically never attained; that ulceration is exceedingly frequent and meningitis therefore the almost inevitable outcome; that not only is the cord below its attachment to the sac practically useless, but the attachment is dragging upon the relatively normal cord above and jeopardizing its function. This is a matter which has not been given due weight in considering the advisability of operating in this type of case, though the traction on the cord has been recognized by all careful investigators, as is shown in the diagrams of my cases. Damage already done cannot be repaired by relief of tension, but at least the conditions can be rendered more nearly normal for the further development which goes on after birth.

Methods of treating the sac.—Stress has always been laid upon the careful dissection of nerve roots from the sac wall, and rightly so, if they be attached to a relatively normal cord. Many observers, however, have recognized that the nerves were inseparably bound to the wall of the sac and have failed to realize the true significance of this. They have not seen in the thickened band of sac roof, to which nerve roots pass, the malformed, practically useless segments of the cord without which the nerve radicles are valueless, and have dissected free roots that could serve no purpose. La Ferte and others, recognizing the importance of preserving the cord, have attempted to turn in the portion of sac wall to which it is attached, with the result that meningitis has

followed with great frequency. When one considers that it is almost impossible to dissect free any of this attached part of cord, and that inevitably one must leave some skin with it if one preserves all the nervous elements, the avoidance of meningitis becomes practically impossible. Nor does it appear to be wise to make this attempt in view of other matters. The cord segments distal to the point of attachment to the sac roof, as shown in this report and in other similar cases reported by previous investigators, are so poorly developed and so damaged by inflammation and epidermal overgrowth, that they are practically functionless; this can be demonstrated histologically and by the neurological examination of the regions normally supplied by them. There is, therefore, nothing to be gained by their preservation. All that can be hoped for is that the segments above the cord lesion may be so far as possible preserved from further harm. To accomplish this the end of the cord must be cut free and allowed to slip up into the canal.

An adherent plug of sac wall left by the operator is comparable anatomically to the adhesion of skin or fibrous tissue to the cord found in spina bifida occulta. Theoretically at least delayed traction or pressure symptoms may be expected here as in the primarily occult cases. Nor can one overlook the danger of an inclusion dermoid developing from the buried epithelial cells of the sac wall. This is especially the case where skin covers or almost covers the whole of the roof of the sac, for in such cases deep skin glands may lie in almost direct contact with the lateral parts of the cord tissue. These delayed effects are not ordinarily reported, because but few cases where the patient survives to adolescence report to the surgeon who has operated, and this is probably particularly true of the cases with new symptoms. Such patients, dissatisfied with the result of the first treatment, are likely to seek some other surgeon who is ignorant of the precise anatomical state and method of procedure at the primary operation. It is difficult to trace successful cases after a number of years have elapsed; it is even more difficult to trace failures. In the light of the anatomical condition in cases with attached cord, therefore, the rational procedure is to cut free the cord as close to sac wall as is possible without leaving any attached inflammatory or surface epithelium, and to injure as little as possible by ligature or by handling the end of this normal cord and the nerve roots attached to it. From purely theoretical reasons it would appear to be preferable to ligate the anterior median vessels with very fine ligatures without including the entire cord, since compression of the cord within the pia must pulp

a considerable portion of it. Exceedingly delicate ligatures and a very fine needle should be used for this, and the ligatures used as tractors to steady the cord while it was being freed from the sac wall. With a view to preserving as much as possible of the healthy cord the line of section should be made parallel with the sac roof and not transversely across the cord.

Attention must also be directed to the nerve radicles which arise from the intra-cystic portion of the cord. Nerve roots in connection with the stretched segments within the sac run in contact with the cord until they reach the roof of the sac. To this they are adherent, and from this course back freely through the sac to their foramina. This fact is demonstrated in Cases III, IV and V. The difficulty in recognizing them is caused by their abnormal direction and adherence to the sac, so that they appear to arise from the involved segments of the cord in the sac wall. If the intra-cystic portion of the cord is carefully examined these roots may be traced from their origin and should then be carefully freed from the sac wall before the cord is cut free. If the anatomical relations are kept clearly in mind the recognition and dissection of these roots should not be impossible under the conditions of operation. The increase in paralysis after operation, often encountered in this type of case, is probably in many instances due to section of these radicles, and not to the section of radicles which arise from the segments of cord which are adherent to the sac wall.

Post-operative recovery.—Except in the cases of spina bifida occulta with pressure symptoms, and in a small number of meningoceles in which there is adherence or traction of the nerve roots but no lesion of the cord, no improvement in function is to be expected as the result of operation. What may be hoped for is that the function of segments above the lesion will not be subjected to further impairment by the traction of fluid or the presence of inflammation. In but few cases even of pure meningocele is there perfect function of the sphincters. This leads one to suspect some cord involvement, perhaps only to the extent that the closed cord is drawn down out of its normal level into the floor of the sac. This probably indicates, as noted in the description of Case VII, that the initial lesion was in the neural ectoderm and that the development of the lower segments of the cord was interfered with to some extent. In operating upon these cases, therefore, one must be prepared for some loss of function of the sphincters, and must remember the great difficulty of determining this accurately in the very young infant. It appears to be practically impossible in many cases to

determine without undue risk to the patient whether the nervous tissue lying in the floor of the sac is the cauda equina, as it should be in a lumbo-sacral tumour, or the end of the cord itself. Nevertheless, this should be determined as nearly as possible, and where there is any doubt in the matter this doubt should be stated definitely in the notes. After reading many case reports in which cord and nerve radicles were said to be absent from the sac, and yet there was incontinence of urine and fæces either before or after operation, one cannot help feeling that some uncertainty existed at the time the observations were made. This is a matter of considerable importance for the surgeon, since the operation which is followed by incontinence where none has been predicted is distressing, and leads the parents to blame the operator though he may not be at fault.

Where there is paralysis of the legs, it may be taken to indicate almost certainly that there is an adherent cord in the sac, and in view of its poorly developed and degenerated condition it may be further assumed that the paralysis is not remediable, even in the rare cases in which circumstances will permit the preservation of part of the degenerated cord. For the purpose of prognosis and also for the advancement of the general scientific knowledge of the subject, the sac wall in such cases should be submitted to systematic microscopic examination. Until this is done and careful reports of the state given with case reports, the results of different methods of treating the sac, and especially the prognosis of different types of case as regards late functional results, cannot be raised above the level of speculation. In this connection it may not be out of place to recall the statistics of Saachtleben (quoted from Harrar), who found in an analysis of thirty cases from the Mikulicz clinic that five only were permanently cured, and these were meningoceles. Harmer in his thirty cases found some paralysis in twenty. This was increased after operation in three; not affected in nine; and improved in eight. Of these eight, five were slightly improved but died subsequently of hydrocephalus or infection. One with pre-operative incontinence showed improvement fifteen months later; one with paralysis of the foot and loss of sensation in both legs recovered from the paralysis but showed no change in the sensory loss; one with paralysis of the legs was well sixteen months later. From this evidence, Harmer concludes that paralysis is in some cases due to traction: a strong argument in favour of operation on cases with attached cord.

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OBSERVATIONS ON CEREBELLAR STIMULATIONS.

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THE question whether the cerebellar cortex is capable of responding to electrical and other forms of stimulation is at present unsettled.

André-Thomas [1], who gives a résumé of the earlier literature, notes that stimulations evoke less constant effects than experimental destructions. He also comments on the great diversity of opinion expressed: some observers attribute definite responses to the various regions stimulated; others deny the excitability of the cortex, whilst admitting it for the intracerebellar nuclei.

The view last expressed is that maintained by Horsley and Clarke [7], who ascribe the results occasionally yielded by cortical stimulation to spread of current to the intracerebellar nuclei. They emphasize a fallacy, which doubtless entered into much earlier work, namely, the facility with which the effects of excitation may be vitiated by current escape to the nucleus and rootlets of the accessorius nerve.

As the outcome of researches on the dog and monkey, Rothmann [9] arrived at conclusions which diverge materially from those of Horsley and Clarke. Stimulating with the bipolar method, the animal being in morphine-ether narcosis, he found the threshold much higher than that of the cerebral cortex. Whilst admitting that some movements of the fore-limb may be due to current diffusion to the intracerebellar nuclei (dentate nucleus), he considers that certain characteristic toe

movements in the fore-leg, elicitable from the anterior surface of the cerebellum, are an expression of genuine cortical excitation. He was able to prove that the impulses concerned in this response are conveyed by the superior peduncles and rubrospinal tracts.

It should be remarked in passing that the conclusions of this writer show but little agreement with the localization theory of Van Rynberk [10]; this theory has more recently been accorded the support of André-Thomas and Durupt [2].

Although Rothmann fails to comment on the mode of causation of the "running movements" ("Laufbewegungen") at times elicitable from the anterior part of the vermis, it is probable that he considers them due to excitation of the cortex. It may be inferred, then, that he regards the cerebellar cortex as excitable.

Beck and Bikeles [3], who repeated earlier experiments of Magnini, conclude that strychnine and phenol are without action on the cortex cerebelli, and, therefore, assert that it is inexcitable.

Shimazono [13], however, applied strychnine to the cerebellar cortex of the pigeon and observed an increase of muscle tonus on the same side of the body.

Beck and Bikeles [4], reverting to the problem, deny any increase of tonus in either pigeon or dog as a result of the action of strychnine on the cortex and, in consequence, reaffirm their original thesis that the cortex is inexcitable.

After denying the excitability of the cortex, the same authors assert, with curious inconsistency, in a subsequent paper [5], that cooling does not depress the *excitability* of the cortex. Failure to mention any definite reactions makes it appear probable that, whatever responses may have been induced, they were excited by action of the current elsewhere than on the cortex (trigeminus, accessorius or nucleus gracilis or cuneatus, *vide* Horsley and Clarke [7]). Such an interpretation would afford a plausible explanation of the lack of change on cooling.

Similar criticisms apply to the conclusions of Bikeles and Zbyszewski [6] that cocaine does not lower the excitability of the cortex.

Consideration of the conflicting statements outlined above reveals the desirability of further evidence regarding the question of the excitability of the cortex cerebelli. The idea that the cortical neurones are excitable appears natural and logical, and its proof demands only the selection of a suitable test reaction, which might be evoked by currents of low intensity, the action of which would extend but a slight distance below the surface.

A reaction fulfilling these conditions was described by Sherrington [11] : when the anterior surface of the cerebellum is faradized there ensues an immediate inhibition of the "decerebrate rigidity" previously evoked by ablation of the cerebral hemispheres. Accordingly, this inhibitory response was employed in the present research as a means of deciding the question whether the cerebellar cortex is excitable.

In the course of this work faradization was applied to the superior cerebellar peduncle in a few instances. The only previous observations on this subject which have come to our notice are those of Thiele [14]. As a result of such stimulation he observed, in particular, movements of the ipsilateral fore-limb consisting of protrusion at the shoulder and flexion at the elbow.

Methods.

The bipolar method of stimulation was chosen in the majority of experiments, since it appeared that the current would be confined to the cortical layers of neurones in a manner scarcely possible in the unipolar method. The platinum electrodes terminated in small beads 1 mm. apart. When precise localization was necessary recourse was had to the unipolar method, the stigmatic electrode being of the usual Sherrington type. The inductorium was operated by two storage batteries; an ammeter and rheostat were included in the primary circuit and the resistance was so arranged that, whilst the hammer was in vibration, the ammeter showed a reading of approximately 0·2 ampère. At 135 mm. secondary distance the current from the bipolar electrodes was just detectable on the tip of the tongue.

The animal (cat) was anæsthetized with chloroform and ether. Tracheotomy was performed and both carotids were ligated. Decerebration was performed with the decerebrator [12], the plane of the section lying about 27 mm. behind the frontoparietal suture, in a cat of medium size. The level of this section, somewhat anterior to that usually employed, was chosen on account of the necessity of preserving the tentorium cerebelli intact. The plane lies usually just in front of the posterior colliculi. Following the decerebration a small serrefine was clamped on the divided basilar artery. The latter procedure permitted of the immediate continuance of the experiment. The head was then supported at a convenient height in a clamp applied either to the lower jaw or to the skull. Precautions were observed to keep the cortex in normal condition by the application of swabs wet with warm saline solution.

Results obtained in Present Investigation.

When stimulation of appropriate strength is applied to the anterior surface of the vermis[1] there results an immediate and general relaxation of the rigidity. The possibility that this inhibition is evoked, to any important degree, from the cut edges of the dura or through the trigeminus may be quickly excluded. The low intensity of the current (100 mm. sec.) and the position of the electrodes in the mid-line render it practically certain that no physical spread can occur to the dural margin or to the trigeminus, both of which are too far distant. Furthermore, we found that the application of 1 per cent. cocaine hydrochloride to the edge of the dura did not modify the reaction in any way. Hence, it may be concluded that the inhibition is evoked from the cerebellar substance.

Possible influence of the current on the internal nuclei in contributing to the effect must next be considered, and the evidence which renders this factor unessential will now receive attention.

In the first place a "healthy" vascular condition of the cortex is necessary for the production of the response by weak currents. The development of anæmia immediately abolishes the reaction. In these respects the cerebellar cortex closely resembles the cerebral cortex. Moreover, the inhibition is elicitable by weak currents (100 mm. sec.), which are, indeed, less intense than those required to excite the cerebral cortex; in one experiment the threshold for exciting hind limb movements from the cerebral motor area was not attained until the secondary coil was at 58 mm. This observation is contrary to those of Beck and Bikeles [5]; the possibility, however, has already been suggested that some, at least, of the reactions described by these writers were caused by current escape to the trigeminus or accessorius, rather than by direct stimulation of the cerebellar cortex. Under these circumstances the current strengths they employed would not indicate the degree of excitability of the cerebellar cortex. In support of such an interpretation of their results, we would mention that we observed that approximation of the electrodes to the vicinity of the trigeminus yields marked postural changes in the ipsilateral fore-leg, and that direct stimulation of the nerve itself with weak currents (200 mm. sec.) causes flexions and claw movements in the same limb.

[1] The terms "vermis" and "lateral hemispheres" are retained in the present paper, since the nomenclature of Bolk and van Rynberk offers no advantages in relation to the problems investigated.

If we admit that the inhibition is called forth in the cortical neurones we may naturally expect abolition of the response by the application of cocaine. Accordingly, the response was induced from the anterior surface of the vermis by a minimal current and a 1 per cent. solution of cocaine hydrochloride containing a little methylene blue was then applied. Stimulation of the original intensity repeated after about one minute yielded no response. It is reasonable to suppose that the influence of the cocaine was mainly on the cortical neurones and that, therefore, the inhibition had been induced as a result of excitation of these neurones.

The evidence given above leads to the logical conclusion that the inhibition is induced as a consequence of a state of excitation in the cortical neurones or, in other words, that in respect to this reaction the cerebellar cortex is excitable.

Sherrington [11] describes the "inhibitory area" as extending over the anterior surfaces of the vermis and lateral hemispheres. With the intention of studying the cortical distribution of the response, we explored the cerebellar surface in other situations. In one experiment small portions of the vermis were successively exposed and each portion was tested with a weak current (98 mm. sec.). It was found that the vermis yielded inhibition from its most anterior part backwards to about 3 mm. above the medulla oblongata; farther than this it was impractical to go, owing to action of the current on the medullary centres. The inhibition affected all four legs; although the remainder of the body was not observed specially, it probably shared in the reaction.

Conclusions regarding the results of faradizing the anterior surface of the lateral hemisphere are only permissible when currents of low intensity are employed. In the case of stronger currents the possibility of diffusion to the cut dural margin or to the trigeminus or accessorius must be considered. Sherrington observed modifications of the rigidity as a result of stimulation of the edge of the dura. He also noted alterations induced reflexly through the trigeminus [11], whilst we ourselves (*vide supra*) obtained changes in limb posture as a result of the action of weak currents on this nerve. Our observations showed that the inhibition elicitable from the anterior surface of the lateral hemisphere reveals itself most intensely in the ipsilateral limbs and more noticeably in the hind-leg than in the fore-leg. Fig. 1 indicates the extent of the anterior cerebellar surface, on one side, from which the reaction was evoked.

The effects elicitable from the posterior surface of the lateral hemisphere have not yet been studied sufficiently to permit of drawing definite conclusions.

In a number of experiments faradization was applied to the superior cerebellar peduncle. In one experiment the cerebellum was removed; subsequently the rigidity first increased and then disappeared completely (cf. Weed [15]). Bipolar stimulation of the right superior peduncle (82 mm. sec.) then yielded rhythmical opening and closing of the claws of the right fore-leg together with running movements in both hind-

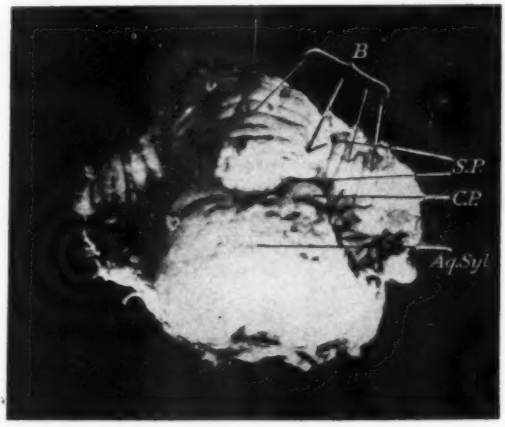

FIG. 1.—Anterior surface of cerebellum of cat. × 2. Aq. Syl., aqueduct of Sylvius B, bristles indicating extent of "inhibitory area" on one side; C.P., colliculus posterior; S.P., sulcus primarius (Bolk).

legs. The unipolar method was then substituted, the indifferent electrode being secured to the left hind-leg. Stimulation was applied to the same situation as in the bipolar method, the secondary being at 100 mm. There resulted the same type of claw movements in the right fore-leg; these movements are very characteristic and resemble those noted in a stroked cat. Because of the attachment of the indifferent electrode the hind-legs were not observed.

A bristle was inserted at the point yielding the reaction just depicted. Sections were prepared and were stained by the Weigert hæmatoxylin method. The bristle is found, on examination, to be situated in the right brachium conjunctivum (fig. 2). The electrode was applied at the point of entrance of the bristle into the brain-stem.

That the effects just mentioned are in reality due to stimulation of the brachium conjunctivum and are not caused reflexly is rendered practically certain, since claw movements of the same character were elicited by faradization of a point in the interior of the cerebellum at a particular stage in its removal. In this instance a tract destined to enter the brachium conjunctivum was doubtless stimulated.

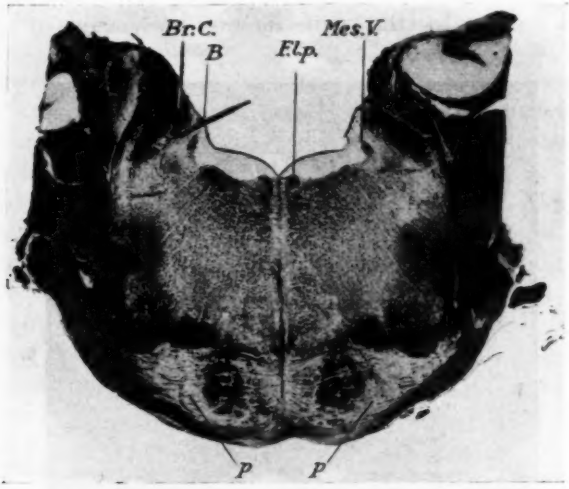

FIG. 2.—Section through the pons of a cat's brain. × 6. *B*, point of entrance of bristle, indicating position of electrode by which claw movements were evoked in right fore-leg; *Br.C.*, brachium conjunctivum; *Fl p.*, fasciculus longitudinalis posterior; *Mes.V.*, mesencephalic root of trigeminus; *P.*, pons.

We may conclude, therefore, that stimulation of the brachium conjunctivum induces claw movements in the ipsilateral fore-leg. With respect to the exact localization of the running movements of the hind-legs evoked by bipolar stimulation, further experiments are in progress.

Thiele [14], whose observations on stimulation of the superior peduncle were cited in the introduction, does not mention the occurrence of reactions like those noted in our experiments.

A variation from the usual inhibitory response of the cerebellum was noted in a few instances. Stimulation of the anterior surface of the vermis over the area outlined in fig. 3 resulted in the following sequence of events.

(1) Inhibition of rigidity in both fore-legs;

(2) Increased rigidity in the right fore-leg and inhibition of rigidity in the left fore-leg;

(3) Walking movements of the fore-legs, during which the increase and decrease of tonus appeared reciprocally in the two legs.

Concurrently with these fore-leg reactions there developed in the hind-legs first walking and later running movements; movements of the claws also occurred in the hind-legs. The running movements recall the "Laufbewegungen" of Rothmann [9].

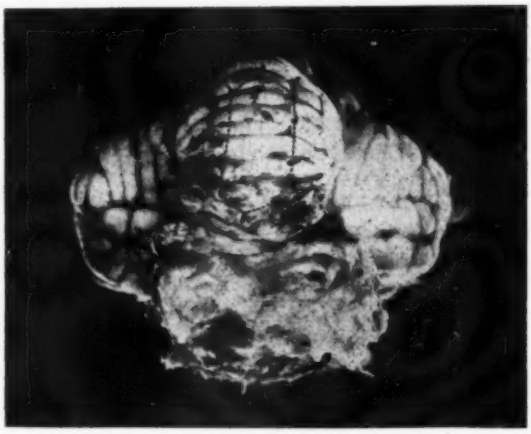

FIG. 3.—Anterior surface of cerebellum of cat. × 2. Faradization of area enclosed by dotted lines yielded walking in fore-legs and walking and running in hind-legs. The figure shows the specimen after removal of part of the mid-brain subsequent to evoking the reactions described.

During the course of another experiment, in which stimulation of the same region yielded mainly inhibition of all fore-legs, it was once noted that a few walking movements of the hind legs resulted.

Since the walking and running movements just mentioned may be evoked with currents of low intensity which at times yield inhibition, and since the inhibition itself has been shown to be a cortical response, it is logical to conclude that the walking and running movements are also an indication of cortical activity. Hence these observations afford additional evidence in favour of our main thesis that the cerebellar cortex is excitable.

SUMMARY.

(1) Evidence is adduced to prove that the cerebellar cortex is excitable. The reaction chosen as a test was the inhibition of decerebrate rigidity evokable by stimulation of the surface of the cerebellum. Reasons are given for concluding that this reaction is induced as the result of a state of excitation in the cortical neurones of the cerebellum.

(2) The inhibition is yielded by the greater part of the vermis in an antero-posterior direction; it is also yielded by the anterior surfaces of the vermis and lateral hemispheres.

(3) Stimulation of the brachium conjunctivum causes claw movements in the ipsilateral fore-leg.

(4) Excitation of the anterior surface of the vermis occasionally elicits, as an alternative to inhibition, walking movements of the fore-legs and walking or running movements of the hind-legs. Since these reactions, like the inhibition, are induced by weak currents, they support our contention that the cerebellar cortex is excitable.

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THREE CASES OF SUPRA-PITUITARY TUMOUR PRESENTING FRÖHLICH'S SYNDROME.

BY CHARLES N. ARMSTRONG, M.B., D.P.H.DURH.

THE three cases about to be described are instances in which Fröhlich's syndrome was present in a more or less pronounced form associated with unusual types of tumour in the base of the brain, none of which started in or infiltrated the pituitary body. In the first two cases the tumour was a cystic ependymoma, and in the third case a cholesterin-containing cyst.

Case 1.—E. H., male, 10 years of age, was admitted to the National Hospital, Queen Square, under Dr. Gordon Holmes, on October 10, 1921, complaining of failing sight, headache and vomiting. His mother stated that the headaches and stiffness of the back of his neck began four months previously: the headaches occurred each afternoon, usually when he was returning home from school. Some weeks later he became subject to vomiting. After the summer holidays he returned to school on September 19, but remained there only a week; it was reported that he was not so bright as formerly and suffered from "heat-waves."

About September 29, after a restless night he complained of severe headaches; his pupils were dilated, he vomited about 10.30 p.m., and again a little later, and became drowsy.

His sight had been deteriorating since August and sometimes he complained of seeing double on looking straightforward. Three weeks before admission to hospital his mother noticed that his left eye squinted, turning inwards. This condition recurred once. During the last few months he had become much fatter.

No previous symptoms had been noticed, except that for the preceding two to three years he had complained of his hands being cold.

Examination.—A finely-featured well-nourished small boy 10 years of age, but he looked younger than his years. Height 3 ft. 10 in.; weight 3 st. He was very drowsy and spoke in a somewhat tired manner with a hoarse voice. His skin was dry and exceptionally smooth and delicate. He was rather adipose generally with a feminine type of fat distribution over hips, abdomen, pubes and chest. The hands were small with long tapering fingers; his feet also were small and finely formed. The external genitalia seemed normal.

No loss of sense of smell was detected. Visual acuity was much reduced

on admission; he could only see the largest letter on Snellen's Chart at bed length ($\frac{2}{60}$), vision being somewhat better in the right eye than in the left.

There was advanced papillœdema in both eyes, the swelling in the right reaching 3 D., and in the left 2 D.

The discs were becoming white and opaque-looking, and their vessels diminished in calibre.

Examination of the fields of vision was very difficult, as patient was very drowsy and difficult to arouse; they seemed reduced in the temporal halves and also to some extent in the nasal halves. The movements of his eyes were full. His pupils were dilated, circular and equal, reacting feebly to direct light and on accommodation. No abnormalities were detected in the function of the other cranial nerves, and the motor and sensory systems and the reflexes were unaffected.

His heart, lungs and alimentary system were normal. The systolic blood-pressure was 106 mm. Hg. Radiographic examination showed that the sella turcica was enlarged, chiefly in the antero-posterior plane. Unfortunately examination of the sugar tolerance could not be made as the administration of glucose caused vomiting.

On October 18, a right-sided parietal decompression operation was performed by Mr. Percy Sargent. About fourteen days later the patient was much improved; he was not so drowsy, had no pain and was brighter. His visual acuity increased to $\frac{2}{24}$.

As the ultimate prognosis seemed hopeless a second operation was undertaken for the removal of the tumour on November 2. The tumour was reached from the fronto-orbital route, the capsule opened and part of it removed by suction.

Post-operative notes.—The patient took small feeds quite well in the afternoon and the evening of the day of operation but did not regain full consciousness. The pulse was rapid and often difficult to feel. He collapsed and died in the early morning of the following day.

Pathological investigation.—A post-mortem examination was made on the same day. On removal of the brain a large tumour was found above the optic chiasma which it displaced downwards. After making a sagittal section through the brain, the tumour was seen to be in the mid-line; it was about the size of a walnut and was attached to the floor of the third ventricle throughout its whole length, and also to the infundibulum from the upper part of which it appeared to arise. The tumour was surrounded by a capsule except where it was united to the upper part of the infundibulum. It was semi-cystic and contained a highly-albuminous yellowish serum with numerous cholesterin crystals and some calcareous matter (fig. 1).

The sella turcica was greatly enlarged, evidently as a result of the absorption of bone, while the posterior wall of the fossa had been pushed backwards by the tumour. The pituitary body itself appeared to be of normal size though flattened by pressure.

A section through the infundibulum and that part of the tumour adjacent

FIG. 1.—*Case* 1. Mesial sagittal section through brain, showing left half of tumour in position.

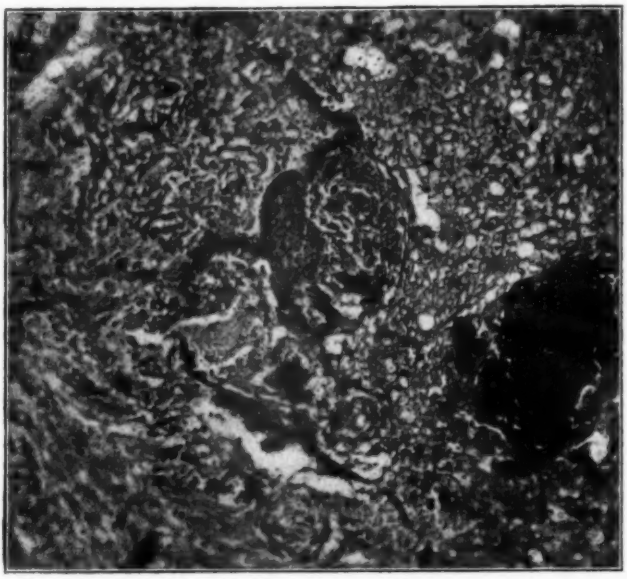

FIG. 2.—*Case* 1. Photomicrograph of section through the infundibulum and that part of the tumour adjacent to it, showing the proliferation of the cells of the ependymal lining of the recessus infundibuli. On the right side of the ependyma the normal neuroglial tissue of the infundibulum can be seen and on the other the cavity of the tumour containing organizing serum and calcareous deposits.

to it shows that the tumour is intimately connected with, and probably originated from, the ependyma of the infundibular recess (fig. 2). On the one side of the ependyma is the normal neuroglial tissue and on the other part of the cavity of the tumour containing organizing serum, some polymorphonuclear and mononuclear cells with pyknotic nuclei, and small areas of calcareous deposit. In the portion shown in fig. 2 the ependymal cells have proliferated and penetrated in both directions, but to a less extent into the glial tissue than into the tumour mass. Isolated clumps of these cells could be seen scattered through the infundibular tissue, while the tumour itself appears to be composed of strands of such cells enclosing spaces filled with serum and fibrin in which there are numerous calcareous deposits. These strands of epithelial tissue run in a matrix which is indistinguishable from glial tissue, and in this tissue run the blood-vessels which are numerous and have thin walls. The outer cells of these epithelial masses are columnar and the others polygonal. The central parts of the epithelial masses tend to degenerate and to be replaced by fibrin or calcareous tissue. The appearance suggests that many of the spaces are formed in this way by disintegration of the tumour.

Case 2.—F. S., aged 35, female, was admitted to the National Hospital, under Dr. Gordon Holmes, on November 29, 1919, complaining of blindness, headache and adiposity. She gave the following history of her illness. Fifteen months previously amenorrhœa commenced; then she began to get fatter, felt tired, and about the same time noticed a slight alteration in her sight. Vision became worse nine months later and occasionally she had diplopia. During the last two weeks vision had deteriorated very much and light irritated her eyes so that she wanted to keep them closed. She had suffered from slight headaches for a long time, especially in the mornings, but they had become much worse during the past month and had been accompanied by vomiting for the last week. She thought that she passed more urine than formerly.

At the beginning of her illness she weighed 11 stone.

Examination.—An enormously fat, but otherwise healthy looking woman; weight 16 st. 6 lb. Her skin was fairly fine, but very dry and soft. There was no alteration in the body hair except perhaps that it was somewhat sparse, but the hair of her head was thick and normal in appearance and quality.

No loss of sense of smell detected Visual acuity of the left eye was $\frac{6}{5}$ and that of the right even less.

Perimetric examination revealed a partial scotoma for white in right inferior quadrant of right eye, and indistinctness of vision in the rest of the temporal field. No scotoma for white was detected in the left eye.

She was unable to recognize red or green in the region of the fixation point in either eye, but her headaches were so severe that complete examination was not possible. Her optic discs appeared normal. Her right pupil was slightly larger than left; both were circular, and reacted to direct and consensual illumination. There was complete paralysis of right external

rectus, the other ocular muscles being normal, but the left eye developed nystagmoid jerks on looking to the right. No abnormalities were detected in the functions of the other cranial nerves, and the motor and sensory systems and the reflexes were normal.

Her systolic blood-pressure was 121 mm. Hg, the diastolic being 82 mm. Hg.

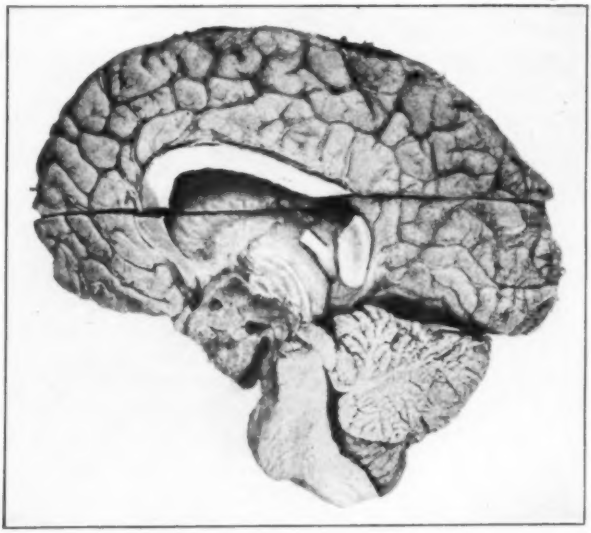

FIG. 3.—*Case* 2. Mesial sagittal section through brain showing right half of tumour in position.

Radiographic examination showed no evidence of enlargement of the sella turcica in the antero-posterior plane, but viewed stereoscopically it appeared enlarged laterally. The sugar tolerance was not above normal, 100 grm. of glucose giving rise to glycosuria.

On January 24, 1920, a right temporo-parietal decompression operation was performed by Mr. Percy Sargent; there were evidences of an enormous increase of intracranial pressure. Patient died five days later.

Pathological investigation.—A post-mortem examination was made on the day after death. On removal of the brain a tumour about the size of a walnut was found in and above the sella turcica. It lay slightly to the left of the mid-line, behind the chiasma which it had pressed forward. In a sagittal section through the brain the tumour was seen to be semi-cystic, and to be attached to the floor of the third ventricle throughout its whole length (fig. 3).

There was very great enlargement of the pituitary fossa, chiefly at the expense of its anterior margin. The posterior clinoid processes were also pushed backwards.

On microscopical examination the tumour tissue is seen to be composed of branching epithelial masses of various shapes projecting in all directions and enclosing cystic spaces (fig. 4). Some of these cystic spaces contain a serous looking substance, and others organizing fibrinous matter. Calcareous deposits are also found within them. The cells of the outer layer of the

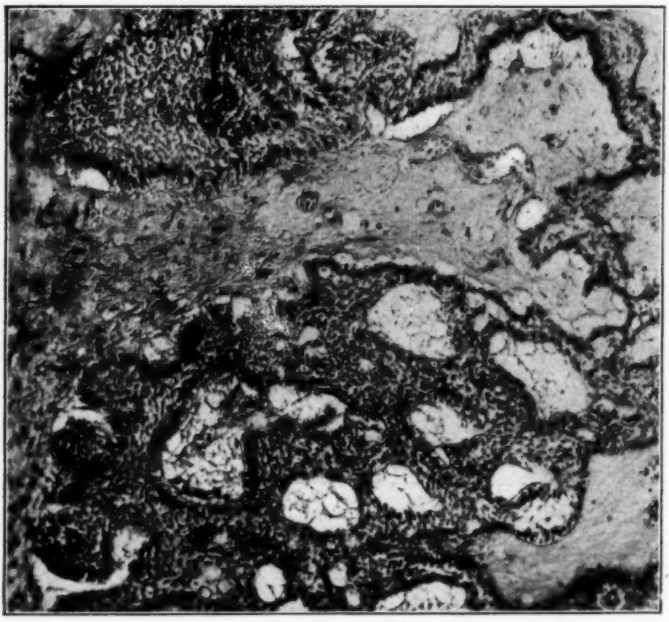

FIG. 4.—*Case* 2. Photomicrograph of section of that part of the tumour adjacent to the infundibulum showing branching epithelial masses enclosing cystic spaces and neuroglial tissue intervening between the epithelial processes.

epithelial masses which are in contact with these spaces are columnar and the more centrally placed are polygonal. Occasionally in the central area of some of the strands the cells are flattened. In that portion of the tumour adjacent to the brain there is a large amount of glial tissue intervening between the branching cellular processes. The blood-vessels are scanty and thin walled; they lie within the spaces and tend to channel the epithelial strands.

Case 3.—W. L., aged 18, female, was admitted to the National Hospital under Dr. Farquhar Buzzard, on February 12, 1920, complaining of headache

and loss of sight. Although 18 years of age she had never menstruated. Two years before admission she had begun to complain of frontal headaches which were worse each morning. She did not suffer from vomiting until twelve months before admission when it commenced accompanying the headaches and having no relation to food. About two months after the headaches began her vision became blurred, so that she could neither see to read nor to thread a needle. Her mother stated that at first she used to bump into people who were walking at her side as she could see only in front of her, and that she had to turn her head to look to either side. She had always been fat; before Christmas, 1919, her face assumed a bloated appearance, but this had become less pronounced. She was rather drowsy and was always dropping off to sleep.

Examination.—The patient was a very fat girl of 18 years who appeared to be only 12 to 14 years of age; she had a childish voice, and was of cheerful disposition. Her skin was abnormally dry and scaly. There was very little body hair, only two to three hairs in the axillæ and very few over the pubis, but the hair of her head was fairly long, thick and silky.

No loss of sense of smell was detected. Visual acuity was so diminished that she could only appreciate coarse hand movements. It was impossible to test her visual fields owing to failure of sight. Ophthalmoscopic examination revealed primary optic atrophy in both eyes. Her pupils were widely dilated, the left being slightly larger than the right. No reaction to light nor to accommodation was obtained in either. Both external and both internal recti were weak,and there was a divergent squint which became a little less marked when she tried to converge. No abnormalities were detected in the functions of the other cranial nerves, and the motor and sensory systems and the reflexes were normal.

The heart, lungs and alimentary system presented no marked abnormalities. The systolic blood-pressure was 100 mm. Hg, the diastolic being 70 mm. Hg. Sugar tolerance: 100 grm. of glucose given orally did not produce glycosuria. Other tests with larger quantities of glucose failed, as the patient vomited. Radiographic examination showed that the sella turcica was much larger than normal.

An operation was undertaken on March 20, by Mr. Percy Sargent. After a frontal osteoplastic flap, hinged in the temporal fossa, was made the frontal lobe was elevated and the tumour reached. A large quantity of yellow fluid containing numerous shimmering cholesterin crystals was removed from it by aspiration. After the operation the patient became almost maniacal, talking incessantly, was very restless and tried to get out of bed. A few days later her temperature began to rise and reached 106° F. An urticarial rash appeared on the back and buttocks. A lumbar puncture was performed and no evidence of meningitis was found. She died on April 2.

Pathological investigation.—A post-mortem examination was made on the following day. On lifting the frontal lobes of the brain, a tumour about the size of a walnut was seen filling the sella turcica with the optic nerves stretched

over it. The sella turcica was appreciably enlarged laterally and antero-posteriorly but was not abnormally deep. An attempt was made to dissect the tumour from the surrounding tissues but in doing so the cyst burst and much brownish fluid with numerous plate-like crystals of cholesterin escaped. A few large solid masses of crystals were also found within it, and one plate of hard calcareous matter was seen attached to the upper wall of the cyst. In a sagittal section through the brain the tumour was seen to lie in the mid-line. The wall of the cyst was firmly attached to the floor of the third ventricle and to the infundibulum from which it apparently had arisen (fig. 5).

A portion of the cyst wall examined microscopically was seen to be formed of fibrous tissue only; no epithelial cell masses could be detected in it.

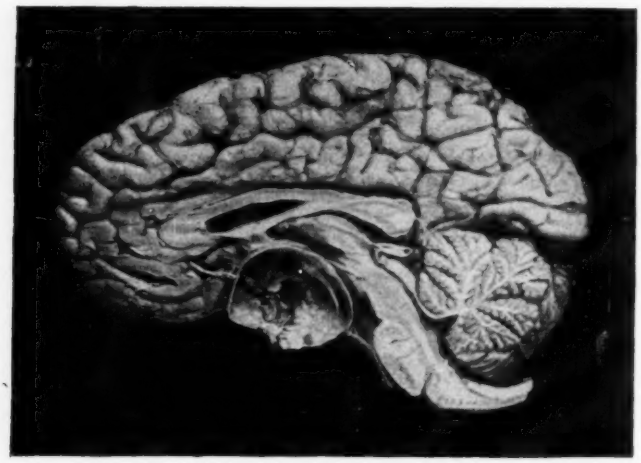

FIG. 5.—*Case* 3. Mesial sagittal section through brain showing right half of cyst in position.

In the first two cases described above the semi-cystic tumours were apparently of the same nature. The tumour tissue was composed of nests and branching masses of epithelial cells, enclosing cystic spaces, the serous content of which was in the process of organization. These epithelial masses were made up of several layers of cells; the basal cell layer being composed of columnar cells while the cells of the superimposed layers were chiefly polygonal. This epithelial tissue appeared to originate by the proliferation of the ependyma lining the recessus infundibuli. In fact this was fairly definitely shown in the first case. The calcareous deposits seen within the cystic spaces seemed to have

been formed as a result of degenerative changes having taken place in the organized tissue within the spaces.

This type of tumour cannot be regarded as being entirely encapsuled, for in Case 1 there was evidence of its extension into the brain tissue near its place of origin.

Similar solid or semi-solid epithelial cell tumours occurring in relation to the infundibulum and third ventricle have frequently been described. The tissue from which this type of tumour originates has always been a matter of some speculation. Mott and Barratt [15] describe two cases, one of which they assumed originated from the choroid plexus, or from the lining epithelium of the infundibulum or of the third ventricle which it filled. Another, which resembled a papilloma, they regarded as an epidermoid cyst developed from misplaced ectodermal cells intended to form the scalp. Here the epithelial structure of the neoplasm bore a very close resemblance to the rete Malpighii of the skin, although no hairs nor fatty matter were present. Langer [10] also described two cases of papillary cysts which he regarded as definitely of infundibular origin.

Hecht [7], in 1909, described a tumour which very closely resembled the tumours in Cases 1 and 2, except that it contained some typical osteoid tissue which, however, may have been a fragment of the sella turcica, since the bone here was markedly corroded and thinned out. In a case described by Otto Kankeleit [9], a remnant of the eroded wall of the sella turcica was found in the tumour. The parenchyma of the tumour described by Hecht was considered to have been formed by proliferating cells of the pars anterior of the pituitary body. The cells formed alveoli-like spaces in a stroma of very loose vascular embryonal connective tissue composed of stellate cells. These alveoli were either completely filled with epithelial cells, or there was present only an outer shell of epithelial cells and an inner mass of hyaline material. The tissue in the interior of the spaces looked somewhat like "epithelial pearls" of cornifying carcinomata, although the material did not show any true cornification. The epithelial cells forming the follicular spaces were cuboidal or short columnar cells. These cells had not only formed the alveolar spaces but had also proliferated in a very irregular manner, and this had led to the formation of irregular masses and tracts of cells. The hard portions of the tumour were composed of very coarse primitive fibrils and fibril bundles which were infiltrated with lime salts. Other parts contained all the osseous elements of bone, corpuscles, Haversian canals, concentric lamellæ and cellular marrow spaces.

Where the tumour was fused with the floor of the third ventricle there was a loose œdematous connective tissue with numerous coarse and delicate wavy fibres forming a wide-meshed reticulum. Dorsal to it was seen a portion of the choroid plexus, the ependymal cells of which had proliferated and formed branching villous excrescences. No cartilage was found in the tumour nor any glia cells or fibres. Hecht regarded this tumour as belonging to that type of teratoma which imitates an entire embryonic region.

The other tumours similar in structure to those of Cases 1 and 2, and which the writers regarded as having possibly originated from the third ventricle, were described by Lereboullet, Morizon and Cathala [11], and the other by Claude and Schaeffer [1]. Cushing [2], Wilfred Harris and Cecil Graham [6], have also recorded cases of cystic epitheliomata of the infundibulum and third ventricle.

Erdheim [3] in 1904 described seven personally observed cases of tumour which he considered to have arisen from "rests" of that part of the ectoderm of the original embryonic buccal cavity which goes to form the cranio-pharyngeal duct. A part of this lies during its final development in the region of the infundibulum and the upper surface of the anterior lobe of the pituitary, and he demonstrated the frequency with which "rests" of the duct occur in this situation by finding them in ten out of thirteen fœtuses examined. These tumours are described as being always in the mid-line and generally originating in the infundibulum. Some were solid but the greater number were cystic and contained a serous fluid in which cholesterin crystals were frequently found. The tumour tissue is described as being epithelial and the cells as resembling those of the buccal mucosa. Both macroscopically and microscopically these tumours appear to resemble very closely the first two described above. Various other observers have followed Erdheim in considering such epithelial tumours to have been derived from the cranio-pharyngeal duct, basing their conclusion partly on the structure of the tumour and partly on its situation.

One of the most striking examples was that described by Farnell [4]. This was a tumour about the size of a golf-ball occurring in the usual situation, in the mid-line and behind the optic chiasma. It had an adeno-papillomatous structure. The remarkable feature of the tumour was that the epithelial tissue not only resembled the buccal epithelium, but even the mandibular type of epithelium composing the enamel-forming organ of the tooth. Hence Farnell regards the tumour not only as a hypophyseal cholesteatoma, but also as an adamantinoma.

comparable to the tumours which develop in the jaw from the dental epithelium. All these cranio-pharyngeal tumours, however, do not present such a typical form of epithelioma. Many of them have been described as being papillomatous, with flat-celled epithelium, and sometimes as containing apparently isolated cell-nests. They thus resemble very closely the structure of the tumours of the first two cases described in this paper. Such neoplasms have also been reported by Harms [5], Kankeleit [9], Mackay and Bruce [14], Strada [18], Lewis [12], and Harry Jackson [8].

The cyst in Case 3, the wall of which contained only fibrous tissue, is evidently of a rarer type. Except that it apparently originated from the infundibulum, its origin is obscure.

There is no doubt that growths of an epithelial nature are the most frequent type of supra-pituitary tumour. Other types of tumours which have occurred in this region are two instances of teratomata and one of an endothelioma described by Cushing [2]. Lockwood [13] records a typical cholesteatoma, Silfvast [17] a glioma and an endothelioma. A case of myxo-chondro-sarcoma was published by Mott and Barratt [15], who also report a very rare instance of mycotic infection which, by irritation, had set up a new growth in the supra-pituitary region.

These tumours occurring in the supra-pituitary region generally produce fairly constant local and general symptoms. The chief local symptoms are those due to involvement of the chiasma and optic tracts, generally producing a bitemporal hemianopsia, and eventually total blindness with optic atrophy if the tumour is not partially removed by operation. In a late stage of the disease there is often increased intracranial pressure, brought about mainly by interference with the escape of cerebrospinal fluid from the lateral and third ventricles. The general symptoms, however, are much more interesting; they generally approximate to the type of dystrophia adiposo-genitalis described originally by Fröhlich. The outstanding symptoms are adiposity, with a feminine type of fat distribution over chest, abdomen, hips and pubes, and either non-development of the secondary sex characteristics if the condition had occurred before puberty, or some loss of them if the condition had commenced after puberty. Hence in cases in which the disease begins in childhood, the genital organs always remain infantile; the pubic and axillary hair never becomes more than very scanty, and in girls menstruation is never established. When the condition sets in after puberty has been established, cessation of menstrua-

tion in women and impotence in men are early symptoms, and the genital organs gradually revert back to pre-adolescent state. There is a very decided diminution in the body hair; the axillary hair often disappears altogether, that over the pubes becomes very scanty. The beard and moustache become thin, or the patient may not need to shave so frequently as previously, although the hair of the scalp does not seem to be affected. The skin of these patients is generally very dry, and extremely smooth and delicate. Metabolism is often, though not always, deranged. Frequently there is an increased carbohydrate tolerance. In other cases, such as those reported by Newmark [16] and by Cushing [2], an outstanding feature was diabetes insipidus. Low blood-pressure, epileptiform seizures, and lowered mentality may also occur. The cause of these striking symptoms has been the subject of much investigation. On account of the involvement of the pituitary gland by pressure of these supra-pituitary tumours, the symptoms have been generally attributed to a diminished secretion of the hypophysis. This theory of hypopituitarism as the cause of Fröhlich's syndrome has been strongly supported by the experiments by Cushing upon dogs. He found that puppies deprived of all their pituitary gland, except a fragment of the pars anterior, became adipose, their sugar tolerance was increased, they remained sexually infantile, and skeletal growth was very greatly retarded. Similar experiments upon adult dogs produced adiposity, increased sugar tolerance, and reversive sexual changes. Further, he observed that animals deprived of only the posterior lobe of the pituitary gland acquired a high sugar tolerance and became very fat, and that intravenous injection of posterior lobe extract produced glycogenlysis, and its continued administration in excessive amounts leads to emaciation.

The exact relation of polyuria and polydipsia to the pituitary gland is still somewhat uncertain, but its occasional occurrence in tumours in the pituitary region indicate that the relation is a close one. Newmark [16] has described a case of severe diabetes insipidus, in which a tumour occupying the region of the infundibulum was found to have destroyed the pars nervosa and most of the pars intermedia. The second case described in this paper had polyuria. It would, therefore, appear as if a destructive lesion of the pars nervosa might result in polyuria. On the other hand, the oral administration of posterior lobe substance in animals had been observed by Schäfer to have a diuretic effect.

There is, therefore, much evidence correlating the state of dystrophia

adiposo-genitalis presented by cases of supra-pituitary tumour with the damage or destruction of the gland. It is also possible that the normal discharge of the posterior lobe secretion into the third ventricle via the infundibular cavity may be interrupted by the involvement of the infundibulum by the tumour. On the other hand, Erdheim believes that the Fröhlich syndrome may be caused by the growing tumour interfering with certain centres at the base of the brain apart from the pituitary gland.

A perusal of the literature on the subject of supra-pituitary tumours shows that about 70 per cent. of these tumours are associated with Fröhlich's syndrome.

The writer is indebted to Dr. Gordon Holmes and Dr. Farquhar Buzzard for permission to publish their cases, and to Dr. Godwin Greenfield for taking the photographs which illustrate this paper.

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THE NERVOUS CONTROL OF THE URINARY BLADDER IN AMPHIBIANS.[1]

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THE experiments described in this paper were undertaken to determine whether the normal evacuation of the urinary bladder in amphibians depended on the integrity of some part of the anterior end of the hind-brain, as has previously been shown to be the case in the cat [1].

The animals used were the common frog (*Rana fusca*), the common toad (*Bufo vulgaris*), the crested newt (*Molge cristata*) and the spotted salamander (*Salamandra maculosa*).

Various proportions of chloroform and ether dissolved in water were tried for the anæsthetic. One c.c. of ether to 100 c.c. of water appeared to be the best, and this mixture was used in the majority of the experiments. The animals were put in a closed glass vessel containing such a quantity of this mixture that they were not completely submerged, and left there till all reflexes, including respiration, were abolished. Though given no further anæsthetic they did not come round till a considerable time after the operation was finished.

After operation the animals were kept till they were killed in a sink into which water was slowly dripping; the surface of the sink was therefore always wet but there was not sufficient water in it to cover them. Most of the animals were kept two days after operation; they were then killed with ether water, the abdomen opened and the degree of distension of the bladder noted. This can easily be determined in frogs during life by a translucent area in the region of the bladder; the same applies to the other animals if a strong light is used. From the observations it seems that two days was an unnecessarily long time, and probably the same results would have been obtained if the period had been one day.

[1] The expenses of this research have been defrayed by a grant from the Dixon Fund of the University of London.

The Effect of Removal of Parts of the Brain.

Portions of the brain were removed in anæsthetized animals by removing part of the roof of the skull, dividing the brain transversely and scooping out the part anterior to the section; the skin incision was then closed. The actual position of the brain transection was determined after death and hardening in formalin by naked-eye examination.

These experiments were made on fourteen frogs, length between 5 and 7 cm.; five toads, length between 6½ cm. and 9 cm.; eight newts, length between 11½ cm. and 14½ cm.; and eleven salamanders, length between 11½ cm. and 15½ cm.

When killed the animals fell into two groups according to the appearance of the bladder; in the one it was tensely distended and marked abdominal distension was present, and in the other, even though containing a considerable amount of urine, its surface always had a crenated appearance; in no case was there ever the slightest doubt into which of these two groups to place an individual animal. Measurements of the bladder contents, though unnecessary, were in most cases attempted by delivering the bladder through an abdominal incision and opening it over a measure. In the case of the frog the figures obtained by this method probably give a fairly accurate idea of the degree of distension. In the toad and salamander the figures usually represent less than the actual degree of distension in the case of distended bladders, since in opening the abdomen a large amount of fluid often escapes from the cloaca. This appears to be due to the absence of a lax skin like that of the frog. In the newt the bladder is so small that the drops adhering to the opened bladder, sides of the measure, &c., may form an appreciable proportion of the bladder contents. In the frogs the normal maximum quantity of urine that can be collected in this way is probably under 2 c.c.; the amounts collected in those with over-distended bladders varied from 3¼ c.c. to 12 c.c. In the toad the normal maximum appears to be up to 10 c.c.; the amounts collected in those with over-distended bladders varied from 10 c.c. to 59 c.c., in the former a considerable quantity was known to have been lost. In the newt the quantities collected from those with over-distended bladders varied from 0·3 c.c. to 1·2 c.c., and in the salamander from 3½ c.c. to 11½ c.c.

Removal of the fore-brain only, with one exception, was never

followed by an over-distended bladder; the exception was a salamander and after hardening the mid-brain was found to have become softened. In all cases where the transection was behind the cerebellum an over-distended bladder resulted. With the exception of one newt, on which not much reliance can be placed on account of the small size of the brain, all cases where the transection went between the cerebellum and the mid-brain resulted in an over-distended bladder. With the exception of one frog in which the whole mid-brain was found to be softened, no experiment resulted in an over-distended bladder where the transection was made through the anterior half of the mid-brain. A transection through the posterior half of the mid-brain was only made in one frog and in it the bladder was not over-distended. If therefore, as is probable, the result in the newt alluded to was an error in observation, the over-distended state of the bladder observed in all four species is due to the destruction of some part of the posterior half of mid-brain.

This localization approximates to that already described in the cat as nearly as could be expected from the methods employed in the two cases. In the cat, however, paralysis of the bladder was shown to be present; in the amphibian the over-distension might be due to this or to failure of the closing mechanism to relax. A third possibility arises from the fact that the ureters do not open directly into the bladder, namely, that the over-distension might be due to some abnormal rate of filling of the bladder. This, however, cannot be the explanation, since in normal frogs it is quite easy to see that the bladder is emptied when urine is passed by the disappearance of the translucent area in the bladder region, whereas in animals with over-distended bladders, even though considerable quantities of urine may escape during struggling when the animal is handled, a large translucent area in the bladder region persists. Though there is no direct proof that the failure of the bladder to empty is due to its paralysis, it seems unlikely that it is dependent on a tonic contraction of the sphincter from the fact already stated that in animals with over-distended bladders comparatively slight mechanical causes can lead to the expulsion of considerable quantities of urine from the cloaca, though the bladder is still over-distended at the end.

The Effect of Division of the Spinal Cord and of the Spinal Roots.

(*a*) *In the Anura.*

Division of the spinal cord in frogs, the species of which is not stated, was found by Exner [3] to lead to great dilatation of the bladder; the level of transection was stated to be at the fourth or fifth vertebra, but it is not given in relation to spinal roots. It was shown by Gaskell [4] that the bladder of the frog, as of the mammal, has a double innervation, the anterior fibres reaching it by the sympathetic and the posterior, which correspond to the pelvic nerve of mammals, arising directly from the sciatic plexus. The spinal roots from which contraction of the bladder could be elicited in the frog were found by Horton Smith [5] to be the ventral roots of the seventh, ninth and tenth, but not of the eighth; the seventh required a stronger stimulus to obtain the effect than the ninth or tenth. Dale [2] showed that in the toad stimulation of the same roots, the seventh, ninth and tenth, and of these only, gave rise to contraction of the bladder.

In the experiment about to be described the first root is considered to be the one emerging between the first and second vertebræ. In many experiments on frogs and toads the lower roots are counted from the posterior end and errors are therefore liable to occur if there is a variation of the normal root arrangement. In the urodela the levels of lesions are given in vertebræ; as the roots emerge from the spinal canal directly they arise from the cord this is not open to objection.

Division of the spinal cord at various levels from the second to fifth roots was performed in six frogs and four toads; in some experiments the cord posterior to the transection was excised, in some it softened and in others it functioned, reflex movements of the hind limbs being obtainable. In all these cases great over-distension of the bladder resulted. The nervous impulse which leads to the normal emptying of the bladder must therefore travel from the posterior half of the mid-brain down the anterior half of the spinal cord.

In two frogs the cord was divided behind the seventh roots and no abnormal distension of the bladder occurred. Division of the ninth and tenth spinal roots was performed in three frogs and five toads; over-distension of the bladder did not result in any case. The toads usually had full bladders when killed but they were always within the normal limits: in the three frogs the bladders were nearly or quite empty. At

any rate the whole mid-brain effect cannot act through the posterior spinal nerves. This appeared such a fundamental difference from the condition in the cat that it was thought the mid-brain influence might be masked by a possible paralysis of the sphincter of the bladder. This was shown not to be the case by dividing the ninth and tenth roots and the cord between the second and third roots at the same operation: flexion of the hips and knees could be obtained then by touching the toes and an over-distended bladder resulted.

Division of the lower spinal roots, excepting the last two, is a difficult operation in the frog and toad, and not an easy one to control by dissection two days after it has been done. It was attempted by removing the laminæ of the four hindmost vertebræ and dividing all roots exposed which emerged in front of the ninth vertebra on both sides. In this way the sixth, seventh and eighth roots were usually divided and the ninth and tenth left intact. In three frogs there was over-distension of the bladder after this operation, but in these there was complete paralysis of all movements of the limbs, including the toes: the ninth and tenth roots, though not actually divided, were therefore not functioning. In one frog in which this operation had been performed, and the ninth and tenth roots of one side divided as well, there was no over-distension of the bladder, but voluntary flexion of the toes of the opposite side occurred during life. In two other frogs, where the sixth, seventh and eighth roots had been divided on both sides, there was no over-distension of the bladder; movement of the toes was seen in one, but in the other no observations were made on this point. In two other frogs the seventh root on both sides, and the seventh and eighth on both sides, were divided and no over-distension of the bladder resulted. Division of the seventh root in frogs does not, therefore, lead to over-distension of the bladder if the ninth and tenth roots are intact even on one side. One experiment only was an exception to this, and does not seem easy to explain: an over-distended (8 c.c.) bladder was present in a frog: anatomical examination showed the ninth and tenth roots intact, and the sixth and seventh roots divided on both sides, the eighth root was intact on the right side, and its dorsal part only divided on the left side: during life there was paralysis of the whole left hind limb except for movement of the toes, but flexion of all joints of the right hind limb occurred. The sixth, seventh and eighth roots were divided in one toad: paralysis of both hind limbs except of the toe movements resulted, but there was no over-distension of the bladder.

In the frog and toad, therefore, both the anterior and posterior sets of roots must be divided to produce over-distension of the bladder; from this it follows that the impulses from the posterior part of the mid-brain which normally prevent over-distension must pass out through both sets of nerves.

(b) In the Urodela.

In two newts division of the cord at the eighth and at the tenth vertebræ respectively resulted in an over-distended bladder.

The nerve roots supplying the bladder in the salamander are apparently not known. Only one experiment was made on this animal. The brain having been destroyed, the laminæ of the eleventh to the eighteenth vertebræ were removed; the cord was damaged in doing this, and it was divided at the level of the twelfth vertebra. It was then stimulated with a unipolar electrode at the posterior border of each vertebra, from the twelfth to the eighteenth inclusive, for about ten seconds; contraction of the bladder occurred when the stimulus was applied at the lower border of the seventeenth vertebra but nowhere else. An attempt was then made to divide this part of the cord into segments and the stimulation repeated with the same current (Kr. 400); the contraction again only occurred at the seventeenth. The stimulus was then increased and the experiment repeated twice again; a marked bladder contraction resulted at the seventeenth vertebra on both occasions and a doubtful one at the fifteenth on one. In this salamander the large roots to the hind limb plexus were the fifteenth, sixteenth and seventeenth; the seventeenth root therefore corresponds to the ninth in the frog and toad. The experiment does not show whether an upper set of nerves exists, and if so where it is, but it is sufficient to show the main part of the lower set arises from the posterior part of the hind limb plexus as in the frog, toad and mammal.

In three salamanders the cord was divided and in all an over-distended bladder resulted. In one the level of transection was the fifteenth roots, the fourteenth being the most anterior large root to the hind limb plexus. In the other two the level was the sixteenth root, and the fifteenth and sixteenth respectively were the first large roots to the hind limb plexuses. It is therefore probable that if an upper set of bladder nerves exists in the salamander only the lower set convey impulses from the posterior part of the mid-brain to the bladder, in which case the salamander differs from the frog and toad in this respect and resembles the cat.

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Proceedings of the Section of Neurology of the Royal Society of Medicine.

President—Mr. Percy Sargent, C.M.G., D.S.O., F.R.C.S.

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Some Varieties of Traumatic and Toxic Ulnar Neuritis.

By E. Farquhar Buzzard.

My interest in the ulnar nerve was first excited in a very personal manner about twenty-five years ago. Having succeeded during the course of a hospital football match in fracturing one of my collar bones, my arm was duly fastened to my chest in a position of extreme flexion at the elbow with results which still live vividly in my memory. After a very few hours I began to experience discomfort in the sensory distribution of the ulnar nerve. At the end of a couple of days the pain and paræsthesia were so intense that I was obliged to beg for the release of my arm from its fixed position. It is quite true that many persons are able to submit to the same procedure without experiencing any discomfort, and it would seem that some anatomical peculiarity was responsible for my distress. At the same time this peculiarity is shared by a good many people, some of whom complain that if they sleep with an arm flexed, they are liable to wake with paræsthesia referred to the distribution of the ulnar nerve.

Neuritis with no Obvious Anatomical Feature.

With this introduction I may refer at once to the first group of cases of ulnar neuritis to which I would like to draw your attention. In this group there is no obvious anatomical feature which can be regarded as a factor in the production of the neuritis. Examination of the nerve at the elbow does not reveal any abnormality in regard to its relations with bony structures, and it lies well protected in the ulnar groove. The complaint may be limited to a transient disturbance

of function as a result of the excessive use of the hand and arm in a flexed position. A good example of this was the case of a lady, aged 33, who complained of complete failure of function on the part of the two ulnar fingers of the left hand occurring on several occasions at the end of a long 'cello recital. She had played the 'cello since she was 5 years of age, and had recently indulged in what may be regarded as excessive hours of practice. But it is possible to produce more permanent ulnar disturbances by excessive use of an arm, as in the case of a man who came to me complaining of numbness in the ulnar fingers of the right hand and slight pain in the region of the elbow. On examination, there was found some loss of epicritic sensibility in the ulnar distribution and slight atrophy and weakness of the ulnar muscles, including flexor carpi ulnaris. At the elbow the nerve seemed to be in good position, and the only abnormality found was slight tenderness just below its exit from the ulnar groove. This condition had apparently been produced by a long spell of fishing with a heavy salmon rod, and any attempt at using a rod or a tennis racket sufficed to renew the pain, and was attended with difficulty in maintaining a proper grasp.

Even less violent exertions may sometimes end in a similar condition. For instance, a lady, aged 43, complained that for three weeks she had had difficulty in using her right hand, and was conscious of a pain like a sting in the ulnar border of the palm and in the two ulnar fingers. The ulnar muscles were obviously weak, but showed very little atrophy, and no definite sensory loss could be detected. The only ætiological factor which I could discover in her case was a period of excessive use of the hand in sewing and writing.

Cases with an Additional Toxic Factor.

Closely allied to the group I have just described is another in which it is possible to find an additional ætiological factor in the form of some toxic agent. In these cases, again, no anatomical abnormalities can be detected, and the most characteristic feature of this form of ulnar neuritis is its onset, while the patient is confined to bed with some infective or septic illness. I saw quite a number of cases of this description during the war, especially among soldiers confined to bed with severe compound fractures and subsequent prolonged sepsis.

Captain G. M., aged 21, sustained a wound of the right leg, which was amputated. He was laid up for three months in bed with septic complications, and after about two or three weeks noticed increasing numbness and

soreness in the ulnar fingers of both hands. The right hand recovered in the course of five weeks, but the left hand showed atrophic palsy of the ulnar muscles, with some sensory impairment in the ulnar cutaneous area.

I am inclined to attribute the ulnar neuritis in these cases partly to the fact that the arms are constantly being used in the flexed position—partly, perhaps, to an undue amount of friction, and partly to the effect of some toxic agent. In civilian life I have seen a precisely similar condition arising bilaterally in a patient who had been in bed for a fortnight with a slight attack of small-pox. All the cases of this kind which I have come across have made a good recovery. Perhaps one ought to include in this group the occasional case of ulnar neuritis associated with glycosuria, and others in which the only ætiological factor of importance appears to be the gouty diathesis. An interesting example of the latter was a patient, aged 61, who came to me complaining of pain in the ulnar fingers and ulnar aspect of the left hand which had come on suddenly eight months previously after sitting out one evening in the garden. I found definite, but slight, wasting of the ulnar muscles and slight impairment of sensibility in the ulnar area. He suffered from gouty eczema, a gouty big toe, and presented gouty deposits in the lobe of the left ear.

Cases with Some Anatomical Peculiarity.

My third group of cases comprises those in which some anatomical peculiarity can be discovered in connection with the relations of the nerve at the elbow. These cases may be subdivided into: (1) those with a history of severe injury to the elbow; (2) those without any history of trauma.

(1) It has long been recognized that ulnar neuritis may develop many years after an injury to the elbow, and this condition has been ascribed to involvement of the nerve in callus or in fibrous adhesions. I have seen a number of cases of this kind, and the outstanding feature has always been the unprotected position of the nerve at the elbow. It would seem that in these cases the nerve is constantly exposed to minor insults and injuries, each one of which may produce very little immediate effect, but which in the aggregate lead to the formation of a fibrous neuroma. This neuroma is generally a fusiform swelling of the nerve due to a large increase of its connective tissue elements. I have never found any evidence of bony pressure, and fibrous adhesions to neighbouring structures are rarely prominent. On the other hand, some fibrous constriction of the nerve is not very uncommon.

Mrs. O., aged 30, gave me a history that two and a half years before our interview she had sustained a violent blow on the right elbow with a tennis racket and that some months later she began to find slight difficulty with her right hand. She was unable to play tennis or use the arm in any strenuous way during the following summer. She complained of pain in the elbow even when writing or using a needle, and I found the nerve at the elbow very easily displaced and over-exposed. It was tender on palpation and there was some impairment of sensibility in its distribution. Mr. Wilfred Trotter placed this nerve in front of the joint in March, 1920, with the result that the patient is now able to use her hand and arm without any discomfort or disability.

Mrs. S., aged 45, gave a five years' history of wasting and weakness of the left hand with slight pain at the left elbow and in the ulnar side of the hand. She displayed almost complete ulnar palsy as regards the intrinsic hand muscles and some weakness of flexor carpi ulnaris. There was only slight sensory disturbance. The nerve at the elbow was thickened and exposed. In this case there was a history of fracture of the left arm at the elbow forty-two years previously. Mr. Trotter operated and found a spindle-shaped neuroma of the nerve at the elbow, and contented himself with transposing it in front of the joint.

(2) There appear to be a number of people whom nature has treated rather shabbily in regard to protection of the ulnar nerve at the elbow. The groove is very shallow, and when the elbow is passively flexed the nerve can be felt to slip out of it and to lie in an exposed position over the inner condyle. These people may escape any serious consequences of their anatomical peculiarity unless circumstances necessitate a more or less strenuous and continued employment of their arms.

A very good example of this type of case was provided by a man, aged 46, who was sent to me complaining of weakness and wasting in the left hand, and with a sensation of numbness on its ulnar side during a period of about four months. On examination I found a very poor ulnar groove and a large thickened nerve easily palpable on the surface of the bone; there was almost complete atrophic palsy of the ulnar muscles, including flexor carpi ulnaris, and partial sensory loss in the ulnar distribution.

The chief exciting factor in this case appeared to be the fact that the patient spent his time driving a two-horse van with his left arm. A possible accessory factor may have been a somewhat excessive consumption of beer. Mr. P. Sargent operated on this patient and found a fusiform swelling involving the whole thickness of the nerve for about three-quarters of an inch. Below this neuroma the nerve passed beneath a dense fibrous archway which constricted it.

I have seen many other cases of this kind, and a particularly interesting example was the following :—

A platelayer was in the habit of swinging a heavy hammer impartially with both arms. When I saw him he was complaining of atrophy and weakness of the muscles of both hands characteristic of an ulnar lesion. Both ulnar nerves were unusually unprotected and mobile at the bend of the elbows and each exhibited a large diffuse neuroma.

This case afforded a good example of difficulty in diagnosis in that he complained of no pain and but little paræsthesia in his hands. Except for the limitation of the atrophy to the muscles supplied by both ulnar nerves, he would have passed for a case of progressive muscular atrophy, the diagnosis with which he arrived in my out-patient room. It is worthy of note that the sensory disturbance in these patients varies very much, but on the whole is less severe than the motor palsy and muscular atrophy.

Differential Diagnosis.

A careful examination should suffice in all cases to distinguish an ulnar palsy from a spinal cord lesion in the form of progressive muscular atrophy or syringomyelia. On the other hand, so much attention has been paid in recent years to the presence of cervical ribs and the interesting clinical phenomena to which they give rise, that cases of the kind I have been describing are not infrequently sent for X-ray examination on the suspicion that a supernumerary rib may be held responsible for the disability. That such a procedure may give rise to confusion rather than to help in diagnosis is well illustrated by a patient whom I saw two or three years ago and who was ultimately operated on by my colleague, Mr. Cyril Nitch.

He was a man 40 years of age, who, seven years before he came under observation, fell off a motor bicycle and injured his right elbow. He was told that there was no fracture of the bone, but the joint was painful for several weeks and for some time he was unable to straighten his arm. He made a complete recovery, but six or seven years later he noticed wasting of some of his right hand muscles and he felt an occasional tingling over the ulnar side of his hand on straightening his arm. This wasting was preceded for a time by a condition of cramp in his fingers when he was writing. On examination there was distinct wasting of the first dorsal interosseous muscle and epicritic sensibility over the ulnar border of the hand was diminished. The ulnar nerve at the bend of the elbow was freely movable and not obviously thickened. This patient had both his elbow and neck X-rayed. The skiagram of the elbow showed an old fracture of the external condyle with downward displacement, but no signs of injury to the internal condyle. The skiagram of the neck revealed a well-developed seventh cervical transverse process on each side and a rudimentary cervical rib on the right. The motor and sensory

disturbance in the hand determined the diagnosis in spite of the cervical rib, and Mr. Nitch exposed the ulnar nerve at the back of the elbow. It was much thickened by scar tissue in the groove behind the internal condyle and was bound down to the latter by firm adhesions attached to its sheath. On palpation the nerve felt tough and fibrous. It was lifted from its bed after dividing the fascia uniting the two heads of flexor carpi ulnaris and was displaced forwards in front of the internal condyle and kept in position by a graft of subcutaneous fat. Within a few weeks the patient had lost all sensory disturbance, and he returned to his work in the East with the intention of continuing electrical treatment to the wasted muscles.

The number of cases which I have very briefly outlined suggests that the ulnar nerve is particularly prone to disturbances of function on what appear to be at first sight slight provocation. Looking for a common factor in these various groups one is struck by the fact that in the majority of cases the ulnar nerve is unprotected by any bony parapet at the bend of the elbow, or so badly protected that during extension and flexion of that joint it is apt to slip in and out of its proper position. During flexion especially it may lie exposed to friction and pressure on the internal condyle. A consideration of many cases seems to justify the conclusion that movement, especially of a strenuous and frequently repeated character, is an important factor in the production of an interstitial neuritis. This moving contact with a bony surface is probably an important factor in producing the symptoms associated with a cervical rib, although I do not think it has been shown that in the latter case the nervous tissue becomes surrounded by a definite thickening of connective tissue. In the case of the ulnar nerve, however, the nervous tissue is constantly exposed to minor injuries, and the neuromatous condition so often found must be ascribed to chronic inflammation of traumatic origin. It is a little difficult to understand why the flexed position of the elbow should in itself give rise to discomfort referred to the distribution of the ulnar nerve, as I believe there is no evidence to show that the nerve is stretched by that posture of the limb.

DISCUSSION.

Dr. WILFRED HARRIS said he also had a peculiar interest in the ulnar nerve since the time when, as a schoolboy of 13 years, his left ulnar nerve was struck at the elbow by a stone thrown by another boy. He had great pain at the time and had constantly received minor injuries to his ulnar nerve ever since. He thought that this was one of the disadvantages of the erect position of man, since this posture necessitates frequent acute flexion at the elbow and stretching

of the ulnar nerve. In some of the carnivora the ulnar nerve passes forwards into the forearm through a foramen in the lower portion of the humerus above the joint and is thereby less subject to stretching. There was one point in the distribution of the ulnar nerve which he wished to emphasize. In some cases the ulnar nerve did not supply the first and second dorsal interossei, and in such cases, unless this possibility were realized, a peripheral ulnar lesion might easily be mistaken for a central one.

Dr. STANLEY BARNES emphasized the nervous origin of the various occupational muscular atrophies. He saw many such cases in his practice in a large industrial centre; some of them exhibited swellings on the nerve trunks. He instanced one case where a lad, now 17 years old, suffered from a severe ulnar neuritis due to a fracture of the internal condyle of the humerus when he was 7 years old. The nerve could be felt running over a promontory, instead of being in a groove. It was difficult to know what to do for this case; every possible measure had been tried except operation, and Dr. Barnes' war experience of resection and suture was not sufficiently encouraging to justify such treatment so long as any muscular power or sensation remained. Occupational neuritis of the ulnar nerve was due in many cases to friction between the nerve and the humerus due to prolonged use of the arm with the forearm flexed. In a few cases he believed that friction occurred higher up between the clavicle and the first rib.

Dr. G. RIDDOCH said that the pain resulting from ulnar neuritis due to bone injury could hardly be connected with the involvement of nerve in callus, since it appeared so very late. He instanced a case where the pain came on fifteen months after the injury. This case had proved very difficult to treat. Alcohol injection of the nerve had given relief for one month, and a recent surgical operation had resulted in complete relief for three weeks, but the symptoms were now beginning to reappear. Dr. Riddoch also commented on the fact that some patients exhibited motor and others sensory symptoms following the same sort of injury.

Dr. HENRY HEAD quoted Mr. Sherren's paper on "Neuritis of the Ulnar Nerve, due to Deformity in the Region of the Elbow-joint" (*Edin. Med. Journ.*, June, 1908). In one of these patients the neuroma was excised, the two ends of the nerve sutured, and a fresh groove chiselled in the back of the internal condyle. Voluntary power began to return in sixty-six weeks and all the muscles acted voluntarily in one hundred and thirty-two weeks. Sensibility was also restored. To-day it would be better in such cases to displace the nerve to the front of the internal condyle. Dr. Head also pointed out that the protopathic supply of the ulnar nerve extended on to the median half of the palm. This was shown by irritative lesions and could be demonstrated in normal persons by applying a faradic current to the ulnar nerve at the elbow; painful tingling extended across the palm almost to the root of the thumb. On the other hand, division of the ulnar caused loss of sensibility over that area alone assigned in the text-books to this nerve.

The PRESIDENT referred to the delay in the appearance of symptoms after

fracture of the lower end of the humerus. He had seen a clerk, aged 30 years, whose recent ulnar neuritis could only be attributed to a fracture at the age of 4 years. A variety of pathological conditions might be found in these cases. Adhesions were often a cloak for ignorance, but he had in one instance seen a case where the nerve had been compressed under the fibrous arch between the two heads of the flexor carpi ulnaris; complete relief had followed the division of this arch. In another extraordinary case, that of a carpenter who could not flex the elbow beyond a right angle without pain, the nerve was found to be normal at operation, but a loose cartilage was found in a synovial pouch lying between the nerve and olecranon process. The removal of this cartilage cured the patient. For the ordinary type of neuritis associated with a fusiform neuroma, it was his practice to make longitudinal incisions in the sheath, and to transplant the nerve in front of the arm. He agreed that resection of the neuroma with suture of the nerve was quite unnecessary in these cases.

Dr. BUZZARD said he had noticed the occasional abnormal distribution of the ulnar nerve first described by Dr. Harris. The post-traumatic cases could not be due to callus formation, but were due to the more exposed situation of the nerve which resulted from the obliteration of the groove in which it was normally protected, and to the increased amount of movement which resulted from this.

Notices of Recent Publications

Die Vergleichende Anatomie des Nervensystems der Wirbeltiere und des Menschen. By Dr. C. U. Ariëns Kappers. II Abschnitt. Mit 320 Figuren im Text und 7 Tafeln. Pp. 705. Haarlem: Bohn. 1921.

The first volume of this book, which was reviewed in a recent number of this Journal, has been quickly followed by the publication of the second and concluding part. Kappers' Comparative Anatomy of the Nervous System of Vertebrates and Man is now complete, and certainly stands without any rival as to the most comprehensive, authoritative and up-to-date textbook on the subject. Lest its title suggest to clinical neurologists and others that it is merely a comparative anatomy and is concerned exclusively with subjects of less immediate interest to them, it must be pointed out that there are few books in which the anatomy of the human brain is so thoroughly and intelligently dealt with.

The first chapter is devoted to the cerebellum, the development of which is traced upwards from its first appearance in petromyzon, where it is merely a correlation centre between the vestibulo-lateral apparatus and more frontally situated mechanisms, to man. Its subdivision, adopted by Kappers, is based largely on the work of his pupil Ingvar, and consequently differs in certain respects from that of Bolk, Elliott Smith and other anatomists, though it is in principle closely allied to them. According to this view the neo-cerebellar parts, to which its increase in size in the higher vertebrates is due, develop in connection with the lobus medius, that part of the vermis which lies between the sulcus primarius and sulcus præpyramidalis, as a result of newly acquired connections with the inferior olives and with the cerebral cortex through the pontine grey matter; while the palæocerebellar components, including the lobus anterior, lobus posterior and formatio vermicularis, remain fundamentally unaltered. An interesting section is devoted to the question of functional localization in the cerebellum, in which the matter is considered from the physiological and experimental as well as from the anatomical point of view.

In the following chapters the midbrain, thalamencephalon, rhinencephalon, corpus striatum and neopallium are dealt with in the same method. One of the most interesting and instructive of these chapters is that which describes the evolution of the corpus striatum and the development of its connections. By following, as the author does, its growth in the succeeding genera of vertebrates, we are enabled to understand not only the rôle it plays in the evolution of the brain, but also the significance of its separate parts and their multifarious and complex connections. This chapter is certainly not easy

reading, but the student who masters it will obtain a better knowledge of the basal ganglia than he can hope to do by any other method of study.

The final chapter is devoted to the neopallium. Here the comparative method has less scope, but the comparison of the different parts of the cerebrum in different genera, and a study of the stages through which each has passed before attaining its final form in the highest vertebrates, throws so much light on structures which we ordinarily know only from a study of human anatomy that we cannot but be grateful to the author for the opportunity which he gives us here of reviewing them in a compact and very readable form.

The volume under review is as copiously illustrated as the first; there are 320 figures scattered through its 705 pages, and in addition seven coloured tables. Specially valuable features of both volumes are the comprehensive bibliographies at the end of each chapter, and the very complete index of subjects and names.

Die neurologische Forschungsrichtung in der Psychopathologie, und andere Aufsätze. By Dr. A. PICK. With 11 Figures in the Text. Pp. 247. Berlin: Karger. 1921.

Throughout a long and fruitful life Professor Pick has always been interested in phenomena which illustrate the relation of mind and body. Such questions as the nature and causes of aphasia, apraxia, katatonia and hallucinations associated with lesions of the brain, have been his constant preoccupation. As one of the few writers on the Continent who have assimilated and understood the doctrines of Hughlings Jackson, he looked upon these mental changes as dissolutions of highly integrated functions and pointed out in what instances they revealed the activity of lower centres, normally kept under control. This he calls the "Neurological attitude in psycho-pathology."

The first 93 pages of his book are taken up with an essay on the value to mental medicine of the psychical changes evoked by organic nervous disease, and all the subsequent pages form examples of this method of approach. Motor and static perseveration are brought into relation with katatonia; apraxia is explained by the work of Leyton and Sherrington on the cortex, and the somewhat similar views of von Monakow are shortly discussed.

The next paper deals with the pathology of linear writing, based on a case of eclamptic psychosis. This is followed by a consideration of the exceptions to Ribot's law, that in disorders of speech the most recent acquisitions, e.g., a foreign language, are first affected. Pick then discusses the psychology of recurrent utterances in aphasia and passes on to deal with what the French have called "palilalie" or multiple repetitions. This he believes to be associated particularly with lesions of the basal ganglia.

The last paper is a description of visual hallucinations, which followed local treatment to his own eye, after the lens had been extracted for cataract. These took the form of letters projected on some surface at a distance, such as the blind, or the cheek of the person to whom he was talking. When they

appeared on a dark surface, they were surrounded by a luminous background. Such obscure phenomena already possesses a considerable and little known literature; this has been collected with the author's well-known care and thoroughness.

Der Balken. By G. MINGAZZINI. Pp. 212. Berlin: Julius Springer. 1922. M. 160.

This, the latest contribution to the series of monographs edited by Foerster and Wilmanns, is an interesting and instructive book which certainly attains the high level of the preceding volumes of the series. In successive sections the author deals with the anatomy and development of the corpus callosum, and with the symptoms which result from its destruction by vascular lesions and tumours, and from its degeneration due to other causes. Finally he discusses its function, especially from the clinical point of view, and points out the important part affections of it may play in the determination of defect phenomena in man. His general conclusion is that the corpus callosum is concerned in the eupraxia of the limbs, especially of the upper extremities; in the integration of spatial perceptions; and in the correlation of the speech mechanisms of the two hemispheres of the brain.

The author has collected together a very large amount of material and has produced a volume which cannot be neglected by the physiologist or clinician.

Functional Nervous Disorders. By DONALD E. CORE. Bristol: John Wright and Sons, Ltd. Price 25s. net.

The originality of some of the views expressed in this book give it an interest to the advanced student of psychological medicine.

The classification of the functional disorders is peculiarly the author's own, and is based upon a conception of etiological factors in mental illness, particularly in hysteria, which is likely to be contested by the majority of psychologists at the present time. The functional nervous disorders are divided into regressive and progressive groups, in the former of which he places hysteria, and in the latter the sympathetic nervous disorders. He subdivides the progressive group further into what he terms the Instinct-Distortion Neuroses and the Memory Neuroses. This classification is based mainly on his conception of the term dissociation, which to him means a non-registration of memory of highly emotional incidents. The obsessional neuroses are attributed to relative inattention, dissociation not being operative in the sense in which he uses this term. He suggests that the involvement of the sympathetic nervous system in cases belonging to the progressive group induces in the course of time organic disease.

He is rather scornful of psycho-analysis and concludes that it is logically inapplicable to the treatment of hysteria, though it may be used in the treatment of what he terms the obsessional form of the memory-neurosis. Few

psychotherapists of experience will agree with his opinion that the most efficient procedure in analysis is a thorough and searching cross-examination, and not free-association. An interesting chapter is devoted to a study of behaviour in man compared with the lower animals; the author arrives at the conclusion that although animals have what we term "body-memory," dependent on visceral dispositions specific to emotional tones, they can in no sense be credited with memory as we commonly understand it.

Dr. Core's views are clearly and carefully reasoned, but a careful study of this book is not likely to diminish the unfortunate confusion of opinion which obtains at the present time with regard to the etiology and treatment of the functional nervous disorders.

Archives of Neurology and Psychiatry. Edited by Sir FREDERICK MOTT. Vol. viii. London County Council. 1922.

This volume contains seventeen articles, all of which except one have been previously published elsewhere, but neurologists and psychiatrists will be grateful to the editor for having collected them together in this accessible form.

A large part of the volume is made up of studies on the pathology of dementia præcox, which are mainly from the pen of the editor. His Morison Lectures on the Psychopathology of Puberty and Adolescence, and his interesting lecture on "Body and Mind: the Origin of Dualism" are also republished here. Dr. Golla's Croonian lectures on the Objective Study of the Neuroses, and Dr. Morowoka's papers on the histology of the choroid plexus in various forms of mental disease, and the effect of exposing the brain to the gamma rays of radium, are also included.

Other interesting contributions are papers on mental defect and criminal conduct by Sir Bryan Donkin, on the neurological aspects of shock by the editor, and on chemical investigations of the cerebrospinal fluid in epilepsy, and on the metabolism in this disease by Mr. Mann.

Anormale Kinder. By L. SCHOLZ. Third edition. Edited by A. GREGOR. Pp. 312. Berlin: S. Karger. 1922.

The study and treatment of abnormal or defective children has been perhaps of recent years more thoroughly developed in Germany than elsewhere in Europe; there attention has been particularly directed to the "social" training of children both at home and in special institutions under the care of adequately equipped teachers and physicians. The system that has been thus elaborated certainly compares very favourably with our more happy-go-lucky methods; it includes the provision of special schools for those who can remain at home, and institutional life for the more defective whose infirmities make it impossible to allow them to mix with the rest of the family.

This book was originally prepared for teachers and officers of institutions

for defectives, as well as for the medical students and practitioners; the additions and modifications it has received from its present editor have been developed with the same aim. It is therefore essentially a practical book. The psychology of the child, the various types of mental feebleness and deficiency, and the physical traits associated with them, are first considered. The following chapters deal with nervousness, hysteria, epilepsy and the various psychopathies, but the most striking and valuable portion of the book is that devoted to treatment, education, and training. It is written simply and directly, and can be strongly recommended to all on whom fall the duties of the care and education of the abnormal child.

Psychology.—A Study of Mental Life. By ROBERT S. WOODWORTH. London: Methuen and Co. 1922.

This book is intended for students beginning the study of psychology, and its aim is to represent to them in simple and reasoned fashion the present state of this very active science. In this aim it succeeds exceedingly well, and it should prove a useful and stimulating textbook on the subject. It has a distinctly physiological setting, which adds to its value as a textbook.

Defining psychology as the science of behaviour, it studies first the simplest forms of behaviour as illustrated in reflexes and elementary forms of stimulus response, and then passes to the discussion of sensations, perceptions and thoughts as the reactions of higher nervous levels to stimuli of different kinds. The "stimulus response" theory is then enlarged to include motives, interests and purposes as predisposing tendencies to the production of the different reactions and responses that constitute behaviour. From this there follows naturally a division of behaviour into native and acquired reactions, and a consideration of these two classes in detail. Several chapters are devoted to the instincts and their accompanying emotions, to feeling tone and the various sensations, to attention and intelligence, until, finally, we come to the discussion of learning and habit formation, of memorizing and the laws that govern the association of mental processes of perception, reasoning, imagination and the will. Last of all there is a chapter on Personality.

The "unconscious" is dealt with adequately, and while very considerable credit is given to the originality and value of Freud's views there is some very sane and unimpassioned adverse criticism, which is not the least valuable part of the book from the beginner's point of view.

Medizinische Psychologie. By Dr. ERNST KRETSCHMER. Leipzig: Georg Thieme. 1922.

Even to students and practitioners who have chosen the mental illnesses as their special department this little handbook will be found of great interest and value. Unlike the majority of textbooks on this subject it does not deal

with the disorders of the mind in a purely descriptive fashion, but treats them on strictly scientific lines as results of disturbances of normal psychological processes.

Acknowledging the debt that psychiatry owes to normal psychology he passes on to a consideration of mental development, paying particular attention to the part played by the emotions, and discusses the theory of ambivalence and the part it takes in complicating the affective life of the individual. The precise position of dream experience is discussed in its relation to the conscious life of the subject, and to that part of it which lies outside the immediate sphere of awareness. From this the author naturally passes on to a consideration of the state of hypnosis, and thence to hysteria and schizophrenia. The chapter on the Instincts is particularly good in that the normal and the abnormal are treated together, bringing home very forcibly the fact that in all divergences from normal behaviour the underlying processes are psychologically unchanged, but inadequate to the immediate reality at the time.

The last chapter discusses fully all the present-day technical methods of investigating mental illnesses from the psychological point of view, and the necessary therapeutic measures. He appears to be sympathetically disposed towards the Freudian technique, but does not rule out other methods.

The Poetic Mind. By FREDERICK C. PRESCOTT. New York: Macmillan and Co. 1922.

The author has applied the results of recent psychological investigations to the subject of poetic inspiration, and has produced a closely reasoned and well informed book. His outlook is primarily literary rather than psychological; psychological concepts are used to elucidate the nature of the poetic impulse without any desire to make a contribution to pure psychology. At the outset the author prepares us for his opinion that the treatment of the poet's mind must result in general conclusions, and not in the scientific formulæ of a fixed science of æsthetics. The poet's fancy springs from the vicissitudes of personal experience, expressed in dream-like form, shaped by imagination and contorted by repression, springing forth to "cleanse the bosom of that perilous stuff which weighs upon the heart."

It is certainly one of the books on psychology applied to art that repays reading; it is well written as befits a literary theme, tentative, sober and suggestive.

Ueber die Bedeutung und Entstehung der Stereotypien. By JAKOB KLÄSI. Pp. 109. Berlin: S. Karger. 1922. M. 30.

Stereotypy, as defined by the author, is the autonomous manifestations of motor, speech or psychical functions reiterated over long periods in exactly the same form, and neither associated with any emotion, nor adapted to any

objectively purposive end. He distinguishes two main types; those of the one group are either determined by hallucinations and can be consequently regarded as forms of defence reaction, or they may be interpreted as ceremonies or incantations for the reinforcing or symbolizing of a rite resulting from a delusion or hallucination. Stereotypies of the other group are relics of a former occupation or habit and were consequently originally purposive; these are distinguished by the fact that they can be easily modified and altered.

This monograph is a valuable study in a difficult and rather neglected region of psychopathology.

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EDITOR.